fermi
national accelerator laboratory

TM-751
2254

MESON AREA BEAMS AND FACILITIES

Meson Department Staff

September, 1977

THE M1 BEAM LINE

S. D. Ecklund
May, 1977

The M1 beam is a three-stage beam capable of transporting charged particles with momentum up to 400 GeV/c. The production angle is nominally 3.9 mr but may be varied (after August, 1977) from near 0 to over 5 mr by steering the incident proton beam. At the first focus, the beam is dispersed in momentum by 30 mm/%. The beam is momentum recombined at and after the second focus. The beam is switched between east and west branches by a 12 mr bend at the second focus. The third stage incorporates a parallel region with two differential Cerenkov counters. This allows π-K-P separation up to about 250 GeV/c (350 GeV/c after August, 1977). An additional threshold or pseudodifferential Cerenkov counter, 100 feet long, is also located in the third stage. Variable collimators are positioned so as to control the apertures and flux of the beam. Profile monitors are located at each focus and at each end of the third stage parallel region.

The basic properties are noted in Table I. A typical optical diagram is given in Figure 1.

*Reference: M1 Users' Guide, S. D. Ecklund, TM-743, May, 1977.

TABLE I

Ml Beam Parameters

Target					
Width		±0.79	mm		
Height		±0.79	mm		
Length		203.0	mm		
Material		Be			
Production Angle	θ_p	3.91	mr		
Lab Angle	θ_v	0.0	mr		
	θ_h	-3.0	mr		
		Medium Tune		High Tune	
Momentum Range	p_{min}	20	GeV/c	20	GeV/c
	p_{max}	250	GeV/c	400	GeV/c
Angle Aperture Limit	$\Delta\theta_h$	+ 0.0 - 0.7	mr	+ 0.0 - 0.5	mr mr
	$\Delta\theta_v$	± 1.4	mr	± 0.6	mr
Momentum Aperture Limit	$\Delta p/p$	± 2.0	%	± 2.0	%
Solid Angle		1.5	μster	0.5	μster
Dispersion at Momentum Slit		30.0	mm/%	30.0	mm/%
Angular Divergence in Cerenkov Region	$\Delta\theta_h$	± 0.1	mr	$\Delta\theta_h$ = 0.05	mr
	$\Delta\theta_v$	± 0.1	mr	$\Delta\theta_v$ = 0.05	mr
Measured Fluxes Per 10^{13} Incident 400 GeV Protons		3×10^{7} @-175		10^{6} @ -280 4×10^{5} @ -300 3×10^{4} @ -350 2×10^{7} @ +300	

PROJECTED M1 HIGH INTENSITY BEAM

T. E. Toohig
September, 1977

Production Angle:	0^{o}
Beam Momentum:	-400 GeV/c to + <400 GeV/c (safety limit)
Beam Intensity:	$>10^{9}$ 200 GeV/c π^{-} per 10^{13} protons
Beam Offset at Entrance to Front End Hall:	~12"
Magnets Available:	Quads
	3Q60 EPB
	3Q120 EPB
	3Q60 Mark II (7.5 kG/in)
	3Q120 Mark II (7.5 kG/in)
	4Q120
	3Q52 Main Ring
	3Q84 Main Ring
	Dipoles
	5-1.5-240 Main Ring B1
	4-2-240 Main Ring B2
	5-1.5-60 EPB
	5-1.5-120 EPB
	6-3-120
Length of Beam To Experimental Enclosure:	$\lesssim 900'$
Spot Size:	≃2 mm rms

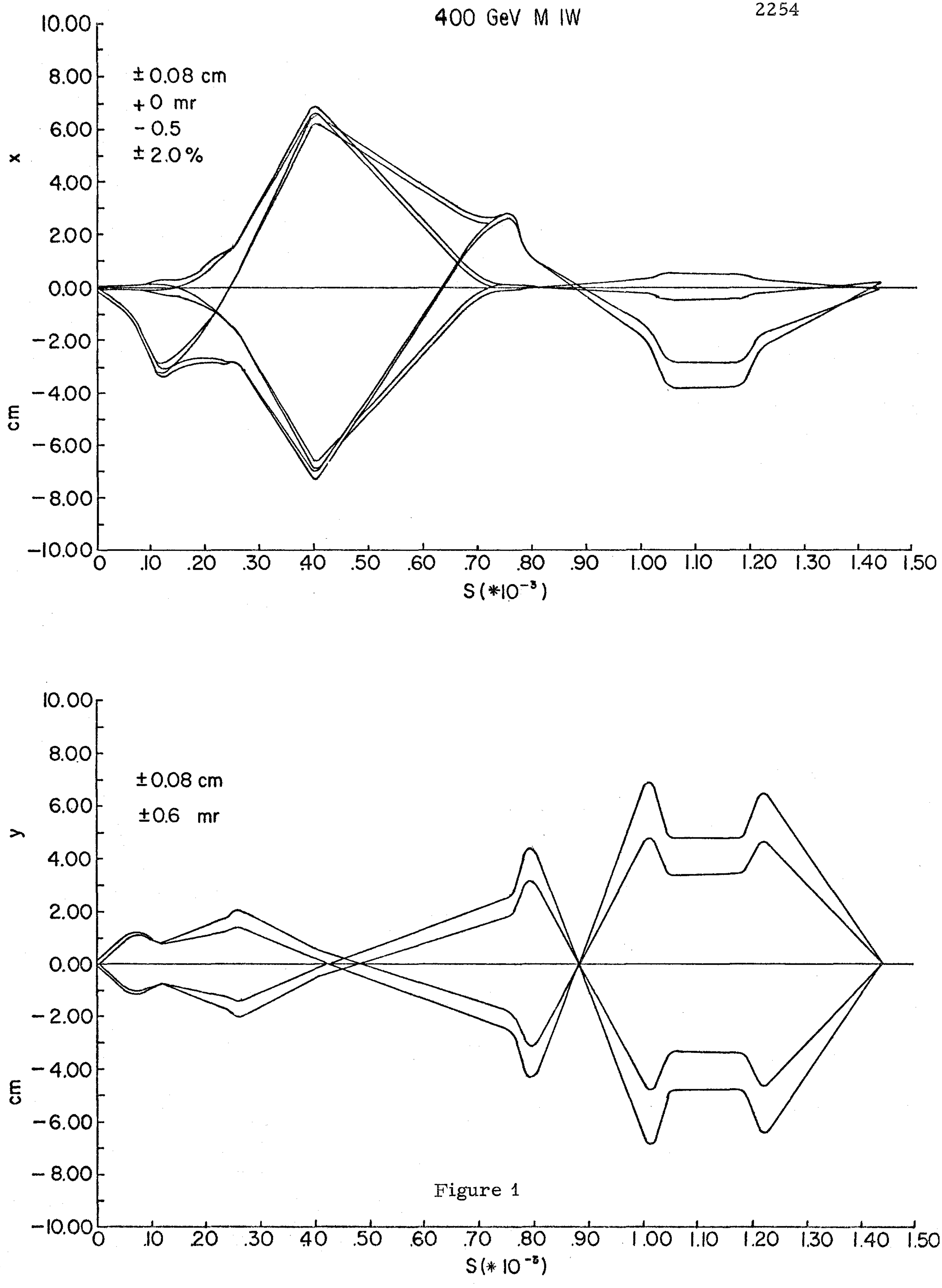
400 GeV M IW
± 0.08 cm
+ 0 mr
- 0.5
± 2.0 %
x
cm
10.00
8.00
6.00
4.00
2.00
0.00
−2.00
−4.00
−6.00
−8.00
−10.00
0
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.00
1.10
1.20
1.30
1.40
1.50
S(*10⁻³)
± 0.08 cm
± 0.6 mr
y
cm
S(* 10⁻³)

Figure 1

THE M2 BEAM LINE

H. F. Haggerty
May, 1977

The M2 Beam line is used primarily as a diffracted proton beam with a nominal intensity of 10^9 protons per 10^{12} protons on target. The beam is also used at lower energies with a maximum yield of about 10^6 positive particles at 100 BeV/c. There are two differential Cerenkov counters in the line to tag particles and there are two profile monitors to indicate beam position and size. The beam is a two-focus system with zero dispersion at the second focus. Final beam spot size is about 3 mm diameter. Some measured beam fluxes and compositions are listed below.

M2 Flux per 10^{12} Protons on Target at 400 GeV/c

Momentum	Yield	Composition
400 (+)	10^9	Protons
300 (-)		1.6% k^-
200 (-)	3×10^5	3% k^-, .7% $\bar{p}$
100 (+)	10^6	
100 (-)	5×10^5	

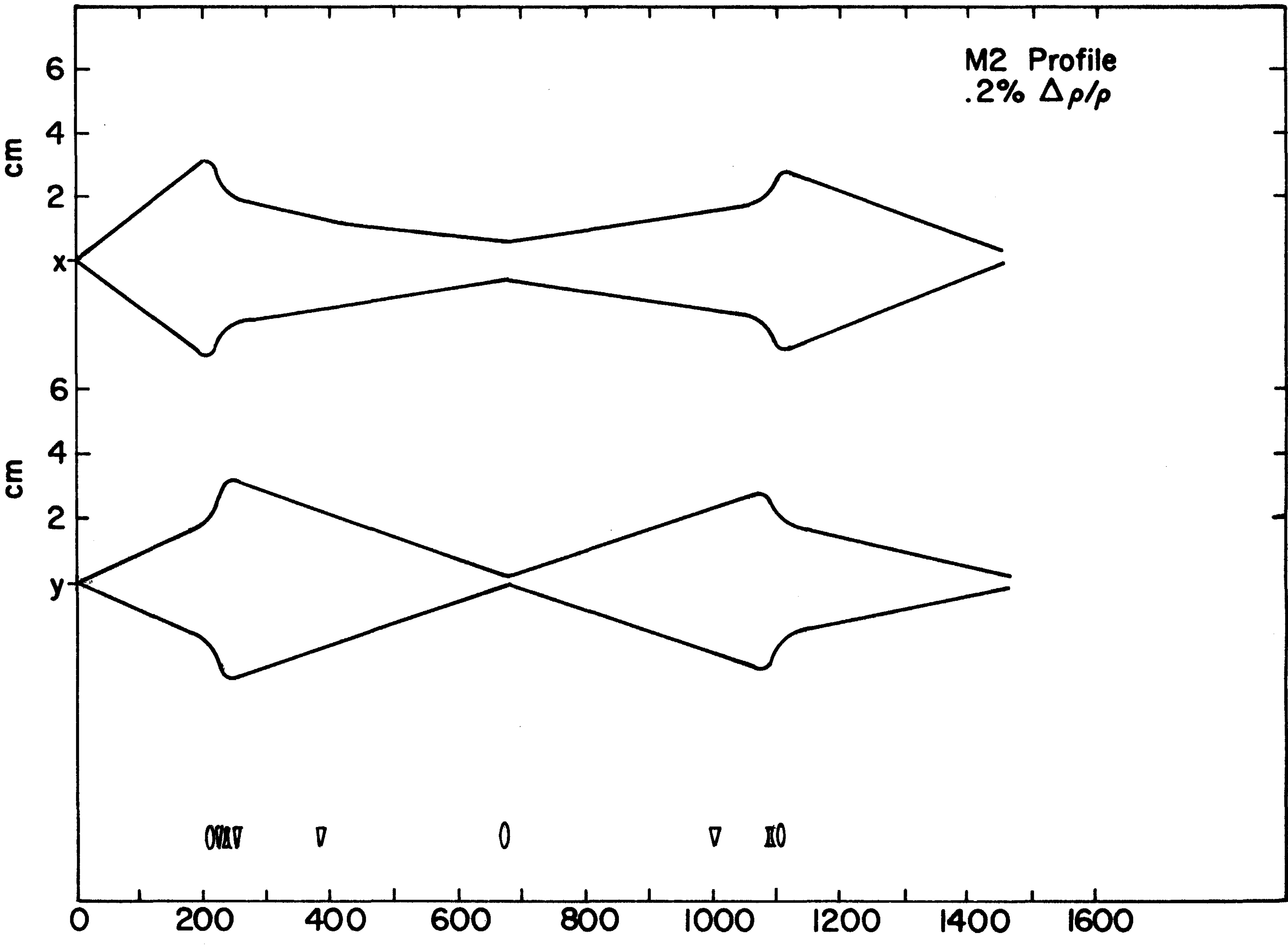
M2 Profile
.2% Δρ/ρ
cm
6
4
2
x
cm
6
4
2
y
0
200
400
600
800
1000
1200
1400
1600

Figure 2

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PRELIMINARY DESCRIPTION OF THE CHARGED M4 BEAM LINE

H. Kobrak
June, 1977

Z			Distance in meters from production target
$\int Bde$			Field integral in kG.M in bender or at 381. mm (1½ inches) from quad axis
Polarity	Benders:	+	Negative particles are bent to beam left
	Quads:	+	Negative particles are focussed horizontally
	X		Distance in cm from "neutral beam line", $X>0 \to$ Beam left
	θ_x, θ_y		Half angle of envelope ($x \to$ horizontal, $y \to$ vertical) in milliradians
	$\Delta x, \Delta y$		Half width in cm of envelope

Fields are for 200 GeV/c particles

The envelope is determined by the C4 collimator (for "on momentum" particles)

The magnifications are:

	x	y
Target to Focus 1:	1.16	2.26
Focus 1 to Focus 2:	2.27	1.35

The spot sizes and momentum spectrum assumes production according to $\frac{dt}{dP_k d\Omega_k} = A\ e^{-(P/31)}$ (P_{in} GeV), which we get from the K^o runs.

Figure 3

Polarity: (+) Bends Negative Particles to Beam Left, Foccuses Negative Particles Horizontally

Z(m)	NAME	$\int B dl$	POLAR.	X	Δ_x	θ_x	Δ_y	θ_y
0	MESON TARGET				0.0	0.375	0.0	0.325
74.85	4Q1	24.43	−	0.0	3.28	3.21	2.14	1.90
78.32	4Q2	24.02	+	0.0	3.87	0.321	1.75	0.144
113.41	4B1	7.56	−	0.0	2.74	0.321	1.25	0.144
116.00	T4V1V	0.0		-0.34	2.69	0.321	1.23	0.144
117.86	4BS4							
200.16	S4C5			-9.83	0.0	0.321	.02	.144
201.68	S4C6			-10.0	.05	0.321	0.0	.144
204.72	4B2	7.56	+	-10.35	.20	0.321	.07	0.144
208.15	4B3	7.56	+	-10.17	.31	0.321	.12	0.144
210.60	T4V2H	.65	−	-10.03	.35	.321	.13	.144
308.12	4B4	7.56	−	0.0	3.52	.321	1.55	.144
310.97	4Q3	8.91	+	0.0	3.49	.916	1.63	.700
312.95	4Q3A	8.91	+	0.0	3.22	2.090	1.810	1.305
315.19	4Q4	8.77	−	0.0	2.83	1.076	2.05	.620
317.16	4Q4A	8.77	−	0.0	2.69	.136	2.12	.107
318.79	T4V3H	0.65	+	0.0	2.67	.136	2.10	.107
320.05	T4V4V	0.0		0.0	2.65	.136	2.09	.107
485.29	4B5	36.2	+	.85	.56	.136	.28	.107
511.89	4B6	36.2	−	.13	.04	.136	.03	.107
516.11	H_2 TARGET			.13	0.0	.136	0.0	.107

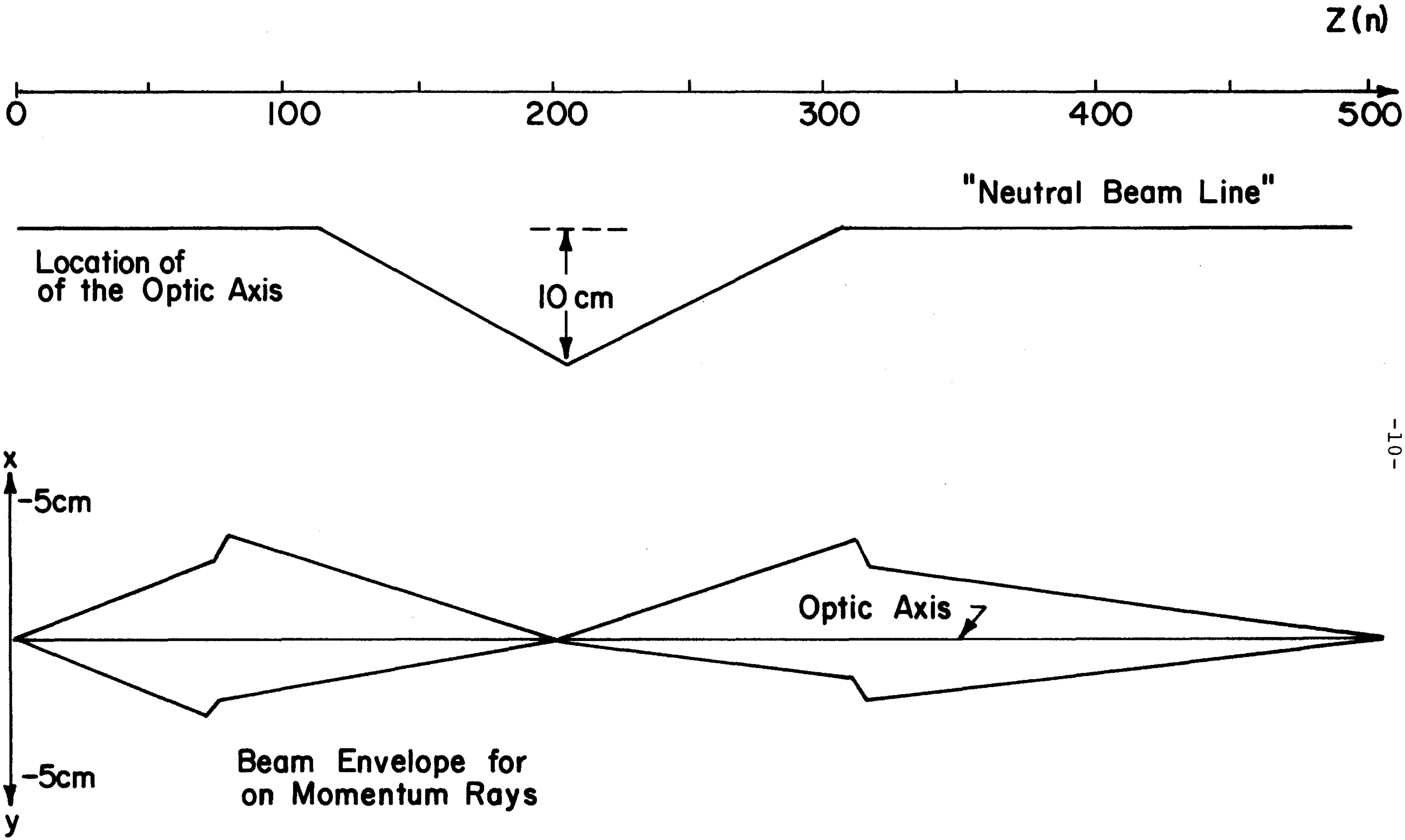

Z (n)
0
100
200
300
400
500
"Neutral Beam Line"
Location of
of the Optic Axis
10 cm
x
-5cm
Optic Axis
-5cm
y
Beam Envelope for
on Momentum Rays

Figure 4

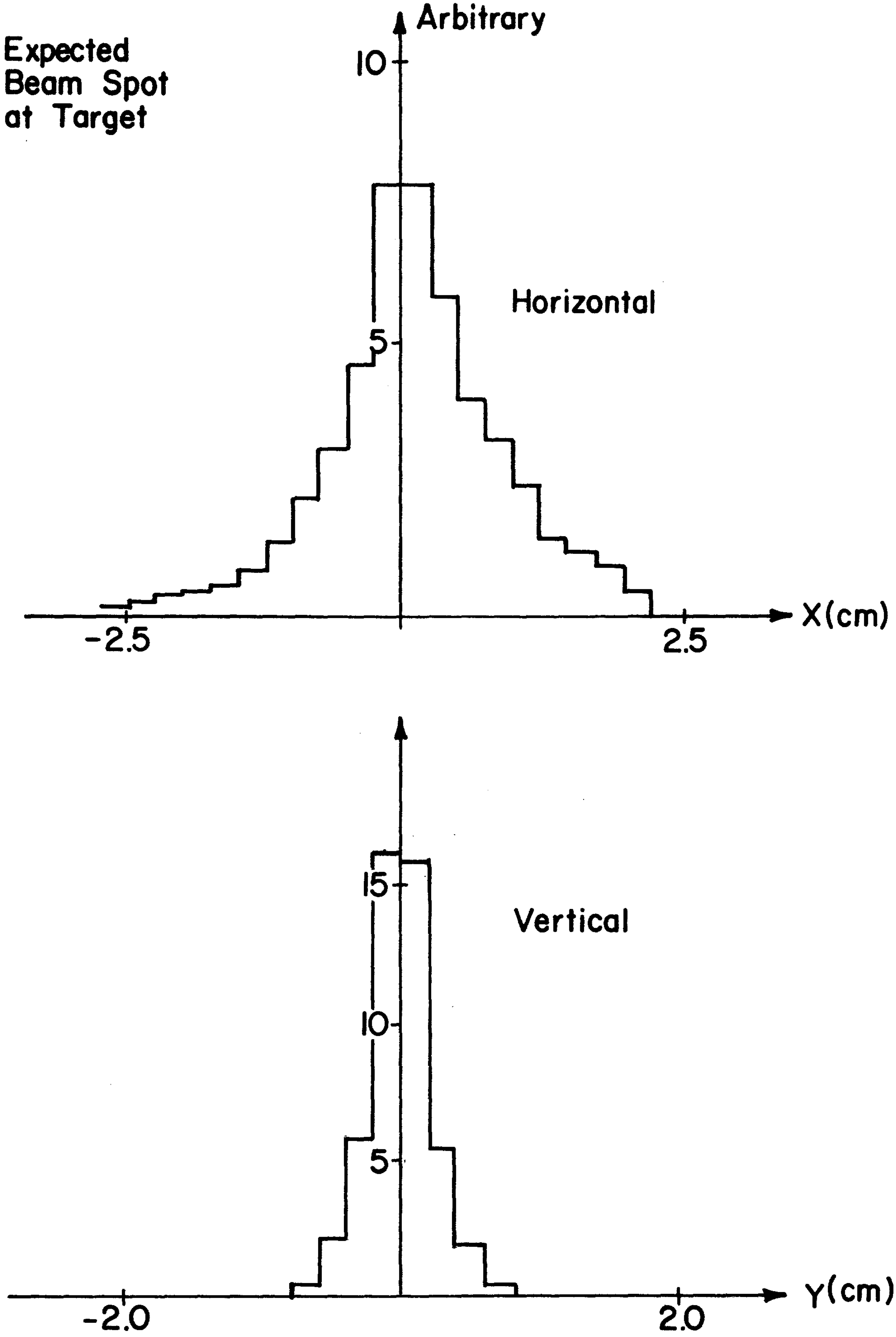

Expected
Beam Spot
at Target
Arbitrary
10
5
Horizontal
X(cm)
-2.5
2.5
15
10
5
Vertical
Y(cm)
-2.0
2.0

Figure 5

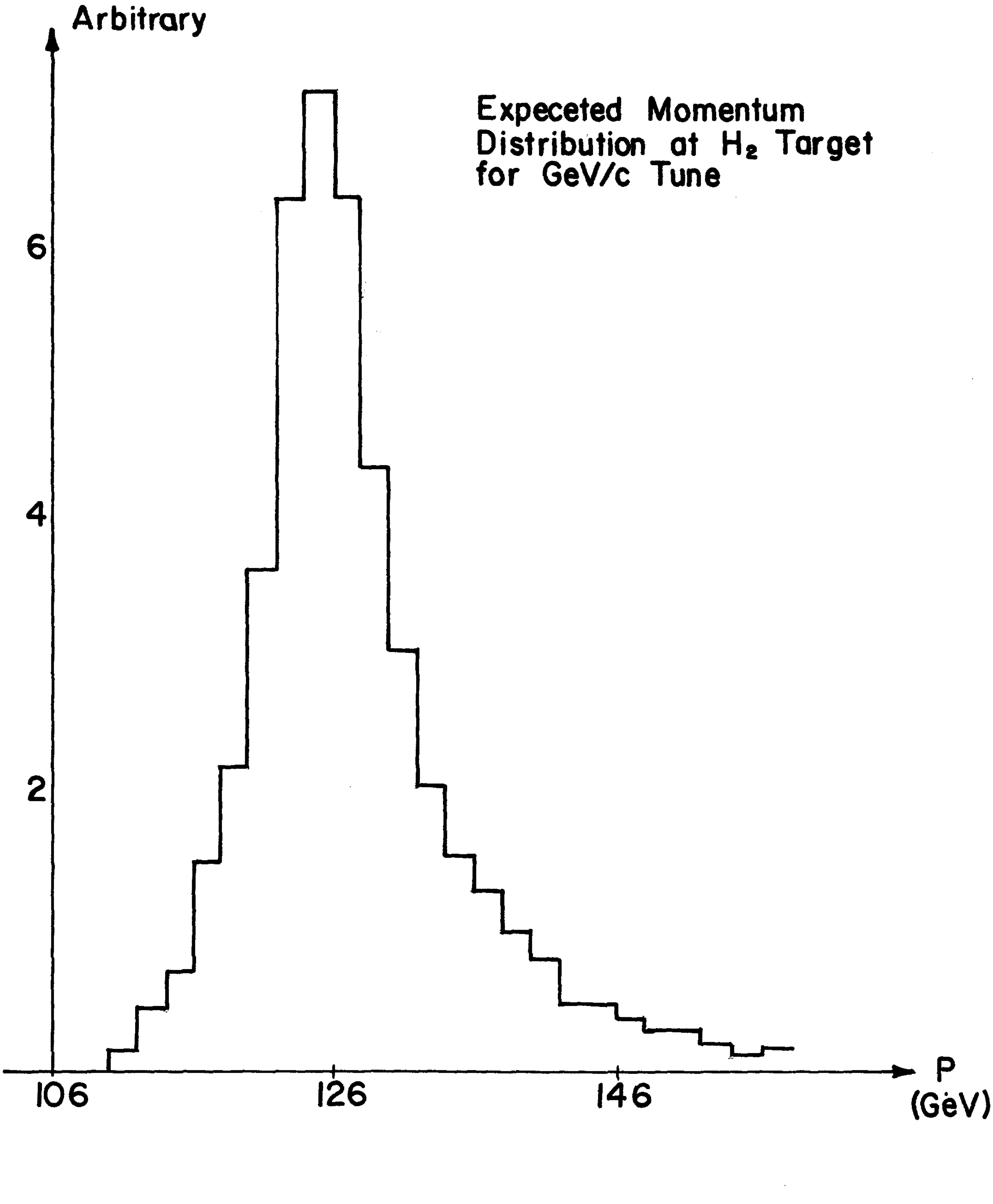

Arbitrary
Expeceted Momentum
Distribution at H₂ Target
for GeV/c Tune
6
4
2
106
126
146
P
(GeV)

Figure 6

THE M5 BEAM LINE

H. F. Haggerty
March, 1977

The M5 test beam is a low energy, low intensity, simple to operate facility. It is intended to be used simultaneously by many users with no waiting list. The experimental area is about 200 feet long and from 6 to 20 feet wide. A 60-foot long threshold Cerenkov and several scintillation counters are provided. Final beam spot size is usually ½" x 1". Most users run the beam at 30 GeV/c where hadron yield is maximum (about 5×10^4 per 10^{12} protons on target). The beam is a two-focus point-to-point-to-point system with a non-zero dispersion at the final focus.

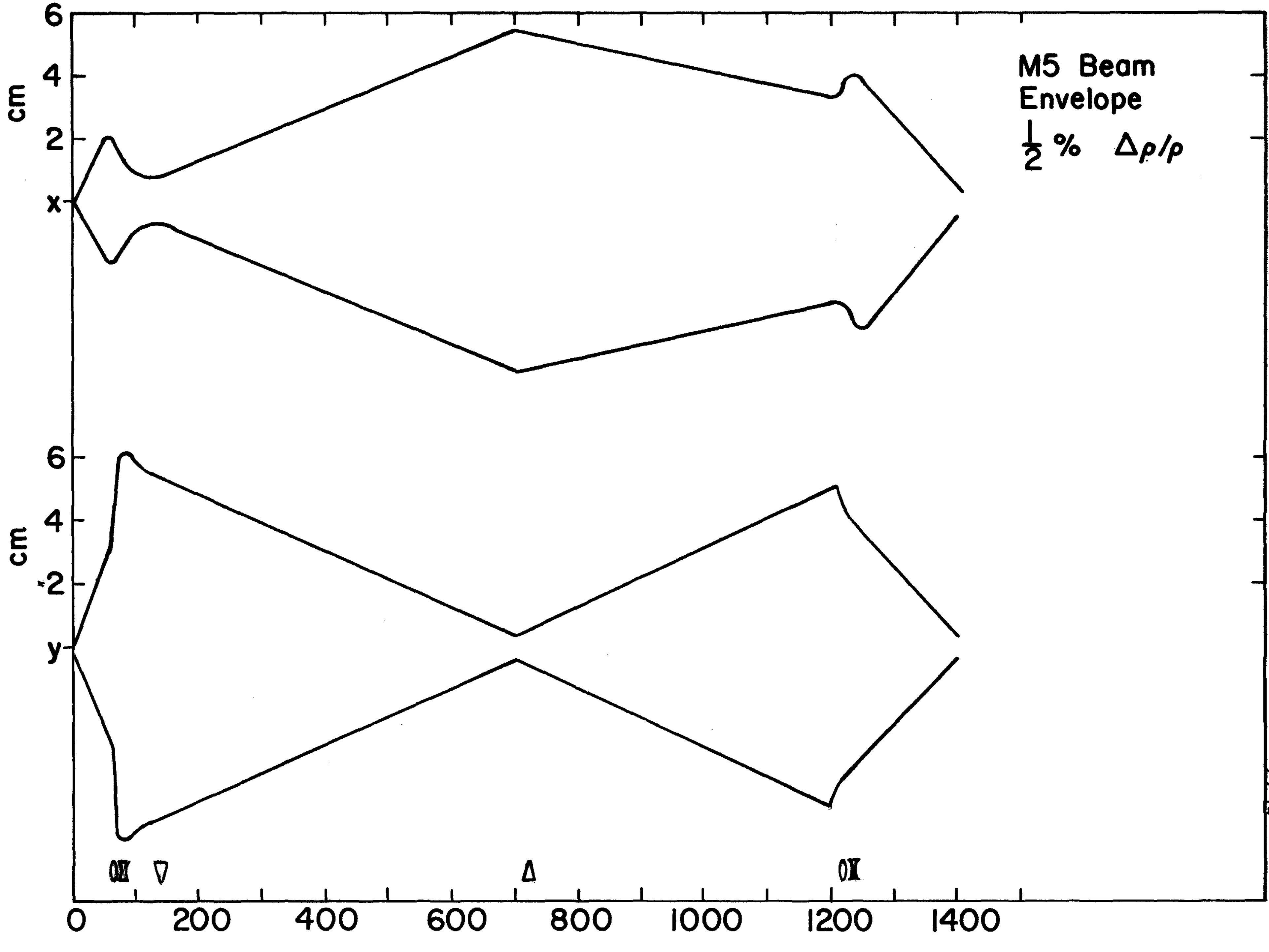

M5 Beam
Envelope
1/2 % Δρ/ρ
cm
x
y
0
2
4
6
200
400
600
800
1000
1200
1400

Figure 7

THE M6 BEAM LINE

E. Malamud
February 2, 1977

Reference: D. Carey, R. Carrigan in Meson Laboratory Design Report, March, 1971

The following updates Parameter Summaries:

M6: S. Ecklund, D. Carey. 16 July 1973
M6 West: S. Ecklund. March, 1973

General

The M6 beam has good momentum resolution, reasonable flux, and has been used over a momentum range of 10 to 200 GeV/c. There are three branches: E, W, and FW. FW and E end in the Detector Building, and have three foci. W has a fourth focus and extends an additional 400 feet to the Multiparticle Spectrometer.

Cerenkov Counters

The beam has four counters for particle identification.

Name	Type	Z Position (center)	Length	Number & Type of Phototubes	Annulus Angle	Max Gas Pressure
"Pruss"	Threshold (but has anti so can be used as differential)	911 ft	96 ft	2-RCA C31000M	5 mr (3.5 available)	15 psig
C_o	Threshold	1079 ft	60 ft	1-RCA C31000M	-	60 psig
BDIF	Differential	1245 ft	45 ft	3-Phillips 56 DUVP	10 mr (7 available)	75 psia
DISC	Differential	1322 ft	19 ft	8-RCA C31000M	24.5 mr	20 atm

Target Size for Listed Properties			
Width		±0.02	inch
Heigth		±0.02	inch
Length		8.00	inch (Be)
Production Angle	θ_p	3.0	mr
Lab Angle	θ_v	0.0	mr
	θ_h	2.5	mr
Momentum Range			
Minimum	$P_{o_{min}}$	10	GeV/c
Maximum	$P_{o_{max}}$	200	GeV/c
Solid Angle	$\Delta\Omega$	1.34	μst
Angular Acceptance			
Horizontal	$\Delta\theta_h$	± .56	mr
Vertical	$\Delta\theta_v$	± .76	mr
Momentum Bite			
Minimum	$\Delta p/p$	±0.014	%
Maximum	$\Delta p/p$	1.0	%
Dispersion At Mom. Slit	$\frac{\Delta X}{\Delta p/p}$	2.48	inch/%
Properties at Experiment	($\Delta p/p$ = ±0.014%)		
Horizontal Width		±0.031	inch
Horizontal Divergence		±0.36	mr
Vertical Height		±0.026	inch
Vertical Divergence		±0.67	mr

Beam Bend Point	Z Center (feet)	X Center (feet)	Angle (mr)	Total Angle (mr)	
M600	0.0	0.0	+ 2.5	2.5	
M610	91.875	0.2297	8.6	11.1	
M620	199.991	1.4298	51.18	62.28	
M630	802.917	39.0287	17.06	79.34	
M640	1189.983	69.8032	-51.18	28.16	
M650	1290.201	72.6261	-34.12	- 5.96	}East Branch
M650	1290.20	72.6261	- 2.99	25.17	}West Branch
M660	1478.76	77.3734	+34.12	59.29	
M650	1290.2	72.6	24.5	52.7	}Far West Branch

Notes:

I. Entire beam line to be under vacuum of 100 microns except where noted.

II. M6AVB1, M6AVB2, M6AVB3 are for changing vertical angle at the East Branch Target

Z Center	X Center	Position Code	Element Code	B/G(kG) or (kG/in)	I(Amp)	P(kW)
0.0	0.0		EPB Target			
20.7	0.05		Fixed Collimator (8.5')			
30.7	0.08		Fixed Collimator (8.5')			
40.7	0.10		Fixed Collimator (8.5')			
85.9	0.22	M6B1	Sept. 4-2-123	9.16	4633.3	178.3
97.9	0.30	M6B2	Sept. 4-2-123	9.16	4633.3	178.3
127.9	0.63	M6V1V	Vert. Vern. 6-4-30	± 3.1	± 125.0	2.9
135.7	0.71	M6Q1	Quad. 3Q120 (on side)	- 4.00	- 84.7	9.6
148.4	0.81	M6C2A	Vert. Collimator 4-48 (Vacuum)			
157.0	0.95	M6Q2	Quad. 3Q120 (on side)	3.45	73.2	7.1
165.2	1.04	M6C2B	Horiz. Collimator 4-48 (Vacuum)			
178.7	1.25	M6B3	Bend 4-2-240	18.64	4827.1	166.3
200.0	1.86	M6B4	Bend 4-2-240	18.64	4827.1	166.3
221.4	2.83	M6B5	Bend 4-2-240	18.64	4827.1	166.3
233.2	3.50	M6BS1	Beam Stop (3.25')			
241.9	4.04	M6Q3	Quad 3Q120	3.53	74.9	7.5
253.9	4.79	M6Q4	Quad 3Q120	- 3.66	- 77.8	8.0
263.3		M6GV1	Vacuum Gate Valve			
265.4	5.50	M6V2H	Horiz. Vern. 6-4-30	± 3.1	± 125.0	2.9
268.0		M6VP1	Vacuum Port Pump			
338.5	10.06	M6P1	Beam Pipe 140.6'			
408.1		M6GV2	Vacuum Gate Valve			
411.0	14.58	M6S1	Spacer 4.7'			
413.9		M6GV3	Vacuum Gate Valve			
476.8	18.69	M6P2	Beam Pipe 127.2'			
540.9		M6W1	Vacuum Window (.008" Al)			
543.9	18.87	M6V3H	Horiz Vern. 6-4-30	± 3.1	± 125.0	2.9
544.7		M6W2	Vacuum Window (.008" Al)			
548.2	23.14	M6C3	Horiz. Collimator (Momentum Slit)			
551.5		M6W3	Vacuum Window			
553.8	23.49	M6Q5	Quad 3Q60	2.53	53.8	1.9
559.4	23.84	M6C4	Vert. Collimator 4-48			
561.6		M6W4	Vacuum Window			
563.45	24.09	M6V4V	Vert. Vern. 6-4-30	± 3.1	± 125.0	2.9
627.7	28.10	M6P3	Beam Pipe 124.8			

Z Center	X Center	Position Code	Element Code	B/G (kG) or (kG/in)	I (Amp)	P (kW)	B/G (kG) or (kG/in)
689.4		M6GV4	Vacuum Valve				
692.3	32.13	M6S2	Spacer 4.7'				
695.2		M6GV5	Vacuum Valve				
710.2	33.60	M6P4	Beam Pipe 49.1'				
749.0	35.66	M6V5H	Horiz. Vern. 6-4-30	± 3.1	± 125.0	2.9	
768.2	36.96	M6Q6	Quad 3Q120	- 4.00	- 84.7	9.6	
782.5	37.75	M6Q7	Quad 3Q120	3.74	79.4	8.4	
790.2	38.23	M6X5	Sext. 4-30		≤ 100.0	≤ 3.5	
802.9	39.09	M6B6	Bend. 4-2-240	18.64	4827.1	166.3	
815.6	40.03	M6X6	Sext. 4-30		≤ 100.0	≤ 3.5	
				East Branch			West Branch
823.4	40.65	M6Q8	Quad. 3Q120	2.93	62.1	5.1	3.4162
845.2	42.38	M6Q9	Quad. 3Q120	- 3.31	- 70.2	6.5	- 4.0693
856.9	43.32	M6V6H	Horiz. Vern. 6-4-30	± 3.1	± 125.0	2.9	
860.9	43.63	M6V7V	Vert. Vern. 6-4-30	± 3.1	± 125.0	2.9	
863.2		M6W4	Vacuum Window				
911.3	47.5		"Pruss" Threshold Counter (95.6')				
979.5	53.07	M6Q10A	Quad 3Q120	0			2.599
976.9		M6W5	Vacuum Window	Continuous Vacuum for East Branch			Second Focus Diagnostics
979.9		S2A,B	Scintillation Counters				
980.0		6PH980 6PV980	Profile Monitor				
982.9		M6W6	Vacuum Window				
1016.3	56.00	M6V8V	Vert. Vern. 6-4-30	± 3.1	± 125.0	2.9	
1019.0		M6W7	Vacuum Window	Second Focus Diagnostics			Cont. Vacuum For West Branch
1022.0	56.44	M6C5	Vert. Collimator				
1024.4	56.65	M6P100	Profile Monitor				
1030.5	57.12	M6Q10	Quad. 3Q120	2.12	45.0	2.7	0
1038.3	57.74	M6Hd1	Momentum Hodoscope				
1041.3	57.97	M6C6	Horizontal Collimator 4-48				
1046.0	58.35	M6V9H	Horizontal Vern. 6-4-30	± 3.1	± 125.0	2.9	
1047.3		M6W8	Vacuum Window (West only)				
1078.6	60.95	$M6C_o$	Threshold Counter (60')				
1108.7		M6W9	Vacuum Window				

Z Center	X Center	Position Code	Element Code	B/G(kG) or (kG/in)	I(Amp)	P(kW)	B/G(kG) or (kg/i
1113.7	63.73	M6V10V	Vert. Vern. 6-4-30	± 3.1	± 125.0	2.9	
1117.9	64.07	M6V11H	Horiz. Vern. 6-4-30	± 3.1	± 125.0	2.9	
1123.4	64.50	M6Q11	Quad 3Q60	- 3.23	- 68.6	6.2	0
1132.9	65.26	M6Q12	Quad 3Q120	- 3.23	- 68.6	6.2	- 3.8694
1152.1	66.79	M6Q13	Quad. 3Q120	4.0	84.7	9.6	3.4899
1168.5	68.03	M6B7	Bend 4-2-240	-18.64	-4827.1	166.3	
1190.0	69.37	M6B8	Bend 4-2-240	-18.64	-4827.1	166.3	
1211.5	70.34	M6B9	Bend 4-2-240	-18.64	-4827.1	166.3	
1222.0		M6W10	Vacuum Window				
1245.0	71.33	M6BDIF	Differential Counter				
1268.0		M6W11	Vacuum Window				

M6 FAR WEST BRANCH

Z Center	X Center	Position Code	Element Code	B/G(kG) or (kG/in)
1279.5	72.4	M6B10	Bend 4-2-240	13.4
1300.9	73.2	M6B11	Bend 4-2-240	13.4
1334.2		M6WV2V	Vert. Vernier 6-4-30	
1349.5		M6W12	Vacuum Window	
1350.3			Hodoscope	
1351.1		M6W13	Vacuum Window	
1415.0			Target	

M6 EAST BRANCH

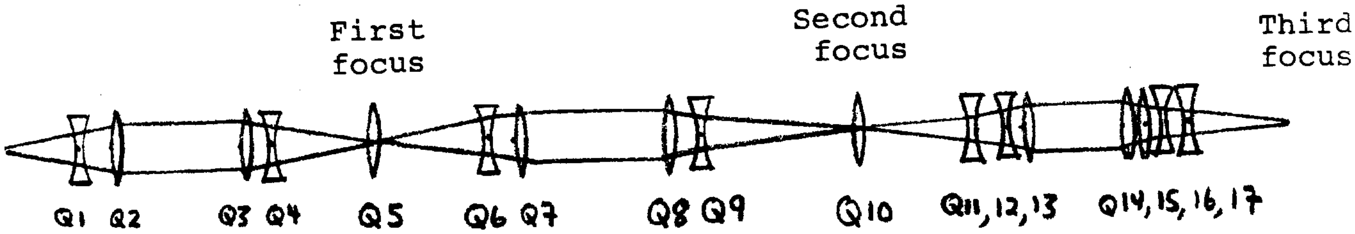
Z Center	X Center	Position Code	Element Code	B/G(kG) or (kG/in)	I(Amp)	P(kW)
1279.4	72.25	M6B10	Bend 4-2-240	-18.64	-4827.1	166.3
1300.9	72.49	M6B11	Bend 4-2-240	-18.64	-4827.1	166.3
1311.9		M6W12	Vacuum Window			
1321.7	72.43	M6K3	Disc Counter (18.5')			
1332.0		M6B3JAW	JAW Scintillator			
1333.0		M6SH1	Shower Counter			
1334.0		M6W13	Vacuum Window			
1348.3	72.3	M6V13H	Horiz. Vern. 6-4-30			
1352.3	72.3	M6V12V	Vert. Vern. 6-4-30			
1359.8	72.21	M6Q14E	Quad. 3Q120	2.32	49.2	3.2
1371.0	72.14	M6Q15E	Quad. 3Q120	2.32	49.2	3.2
1382.3	72.08	M6Q16E	Quad. 3Q120	- 3.07	- 65.2	5.6
1393.5	72.01	M6Q17E	Quad. 3Q120 (magnetic shielding - down stream end 3/4")	- 3.07	- 65.2	5.6
1398.4		M6W11	Vacuum Window			
1400.4	71.96	M6Hd2	Angle Hodoscope			
1402.0		M6W13	Vacuum Window			
1411.0	71.90	M6AVB1	Bend 4-2-120 (on side)			
1443.9	71.70	M6AVB2	Bend 4-2-240 (on side) (magnetic shielding - downstream end 1½"			
1454.3		M6W14	Vacuum Window			
1455.4	71.64	M6Hd3	xy Hodoscope			
1456.5	71.63	M6T2	Trigger Counter			
1457.2		M6W15	Vacuum Window			
1462.6	71.59	M6AVB3	Bend 4-2-120 (on side) (magnetic shielding - both ends 1½")			
1468.0		M6W16	Vacuum Window			
1468.6	71.56	M6BT3	Veto Counter			
1470.0	71.55	M6T2	Hydrogen Target			

M6 WEST BRANCH

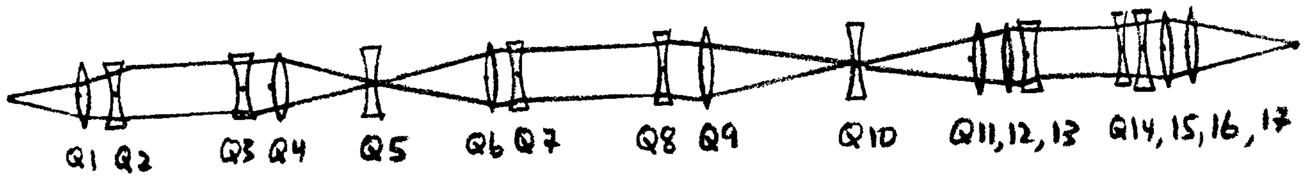
Z Center	X Center	Position Code	Element Code	B/G(kG) or (kG/in)
1279.5	72.31	M6B10	Bend 4-2-240	-1.635
1300.9	72.89	M6B11	Bend 4-2-240	-1.635
1311.9		M6W12	Vacuum Window	
1321.7	72.43	M6K3	DISC Counter (18.5')	
1334.2	74.0	M6WV2V	Vert. Vern. 6-4-30	
1359.8	74.7	M6Q14	Quad. 3Q120	3.4277
1382.3	75.2	M6WQ15	Quad. 3Q120	- 4.1516
1389.9	75.4	M6WV1H	Horiz. Vern. 6-4-30	
1468.2	77.19	M6WB12	Bend 4-2-240	18.67
1489.2	78.08	M6WB13	Bend 4-2-240	18.67
1501.0		M6W13	Vacuum Window	
1502.0	78.75	6PH150, 6PV150	Third Focus (profile monitor, scintillator S3)	
1503.0		M6W14	Vacuum Window	
1620.5		M6W13	Vacuum Window	
1626.8	86.16	M6WQ16	Quad. 3Q120	- 4.00
1635.5		M6C7H	Horiz. Collimator (4')	
1639.5		M6BS2A	Beam Stop (3')	
1643.0		M6BS2B	Beam Stop (3')	
1645.0		M6W14	Vacuum Window	
1650.2	87.55	M6WQ17	Quad 3Q120	3.3619
1659.0		M6WV3H	Horiz. Vern. 6-4-30	
1664.5		M6WV4V	Vert. Vern. 6-4-30	
1700.1	90.51	M6WQ18	Quad. 3Q120	3.3619
1723.5	91.90	M6WQ19	Quad. 3Q120	- 4.000
1738.0			Fourth Focus (E396)	
1809.0		M6WQ20	Quad. 3Q60	
1814.0		M6WV5V	Vert. Vern. 6-4-30	
1817.5		M6WV6V	Vert. Vern. 6-4-30	
1823.0		M6WQ21	Quad. 3Q60	
1848.3	99.31	6PH180, 6PV180	Fourth Focus (MPS Profile monitor	

East Branch

Horizontal



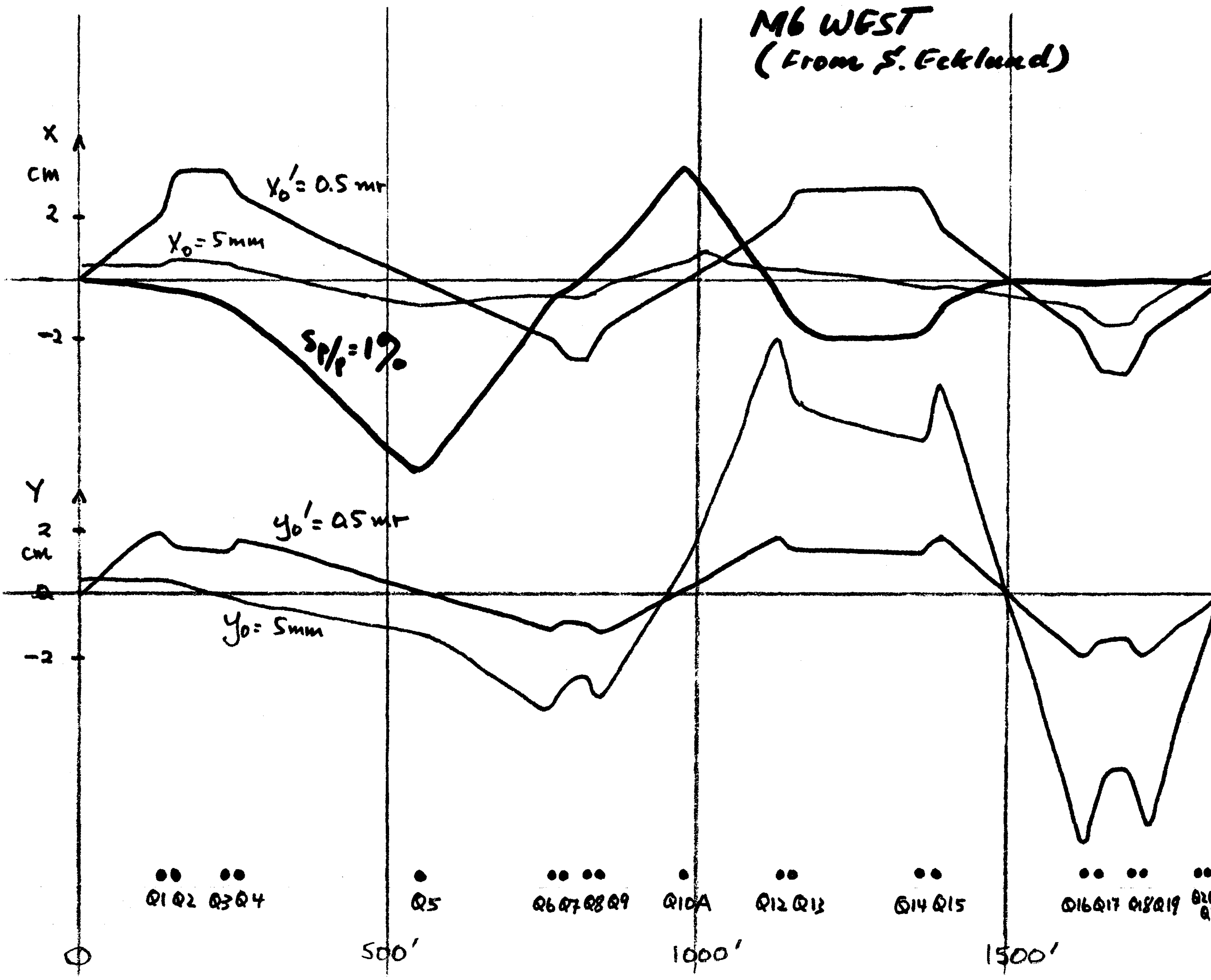
Vertical



Beam Fluxes   Approximate Flux at MPS (Fourth Focus)

per 10^{12} incident 400 GeV protons

	Positives	Negatives
10 GeV/c	10^3	10^3
25 GeV/c		10^4
50 GeV/c		2×10^5
100 GeV/c	2×10^6	10^6
200 GeV/c	3×10^6	10^6


M6 WEST
(From S. Ecklund)
X
cm
2
-2
$x_0' = 0.5$ mr
$x_0 = 5$ mm
$\delta p/p = 1\%$
Y
2
cm
0
-2
$y_0' = 0.5$ mr
$y_0 = 5$ mm
Q1 Q2 Q3 Q4
Q5
Q6 Q7 Q8 Q9
Q10A
Q12 Q13
Q14 Q15
Q16 Q17 Q18 Q19
Q20
Q21
0
500'
1000'
1500'

HADRON COMPOSITION AT THE BEAM AT THE THIRD FOCUS

300 GeV Incident (from J. Elias)

p_{sec} =	50	70	100	140	175	GeV/c
π^+	.760	.650	.401	.210	.106	
K^+	.025	.032	.031	.026	.016	
P	.215	.318	.568	.764	.878	
π^-	.939	.938	.938	.950	.962	
K^-	.026	.032	.041	.041	.034	
$\bar{p}$	.035	.030	.021	.009	.004	

400 GeV Incident (X-Scaling)

p_{sec} =	50	70	100	140	175	200	GeV/c
π^+	.802	.745	.620	.366	.246	.181	
K^+	.029	.036	.042	.037	.032	.025	
P	.169	.219	.338	.597	.722	.794	
π^-	.936	.931	.929	.934	.940	.947	
K^-	.028	.036	.043	.047	.047	.045	
$\bar{p}$	.036	.033	.028	.019	.013	.008	

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MULTIPARTICLE SPECTROMETER

AT

FERMILAB

This note describes and gives relevant parameters of the Multiparticle Spectrometer at Fermilab. The apparatus described here was designed and built by members of the E-110/260 Collaboration.*

Prepared for the MPS Workshop to be held March 4-5, 1977 at Fermilab.

- A. Dzierba (Indiana)
- E. Malamud (Fermilab)
- D. McLeod (Univ. of Illinois)

*C. Bromberg, G. Fox, R. Gomez, J. Pine, S. Stampke, K. Yung (Caltech); A. Dzierba, W. Kropac (Indiana University); V. Ashford, H. Haggerty, R. Juhala, E. Malamud, S. Mori (Fermilab); S. Erhan, E. Lorenz, M. Medinnis, J. Rohlf, P. Schlein (UCLA); R. Abrams, R. Delzenero, H. Goldberg, S. Margulies, D. McLeod, J. Solomon, F. Lopez, R. Stanek (University of Illinois, Chicago Circle). In addition, significant contributions were made by J. Lyvers (Caltech), K. Komisarcik (Indiana), H. Janelli and R. Wall (Fermilab).

PLAN VIEW OF THE MPS

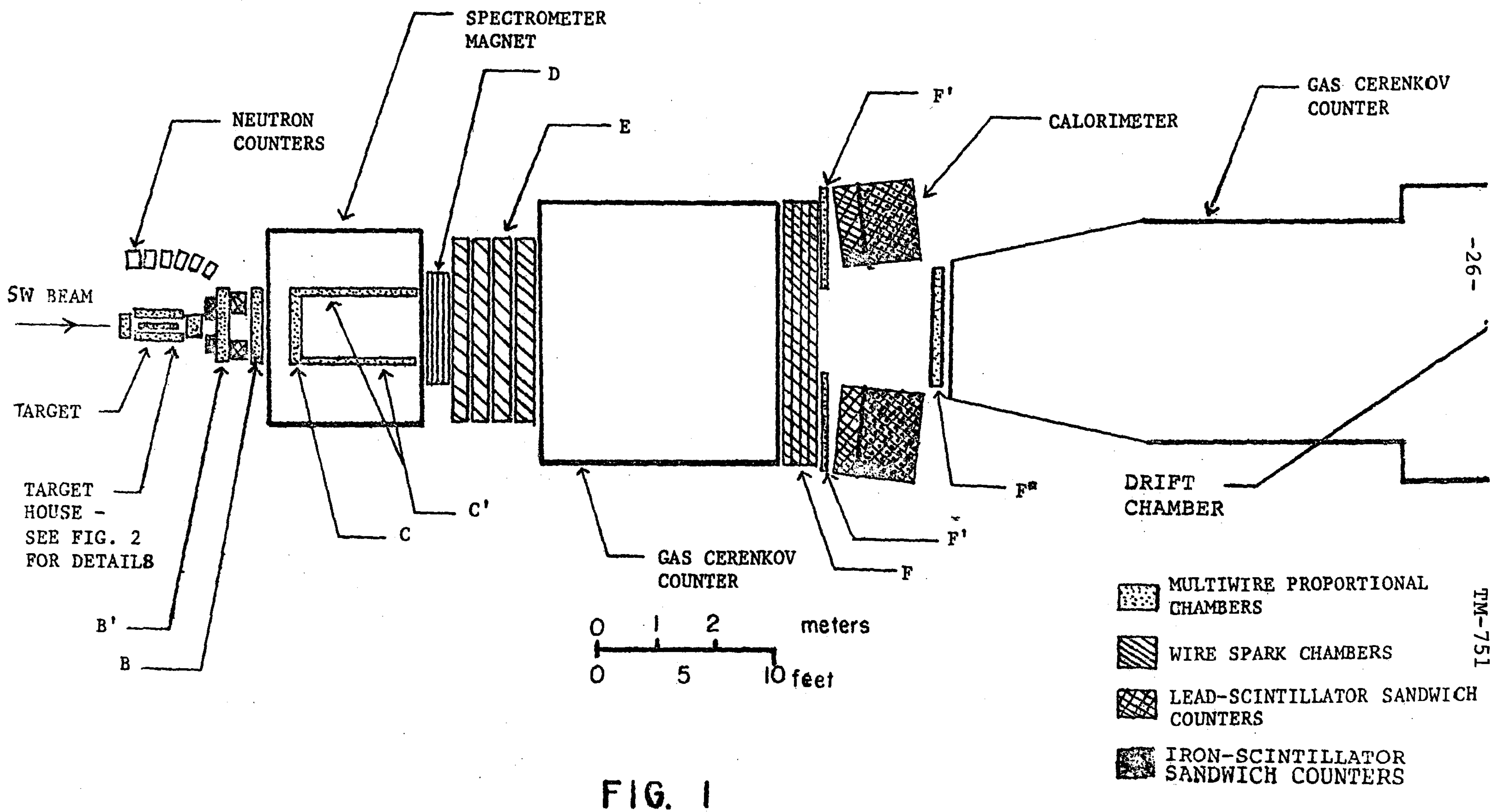


FIG. 1

Overall View

Figure 1 shows an overall view of the MPS. The region around the target house is shown in more detail in Figure 2. In order to give a detailed description of the apparatus, we divide the MPS into its main components and treat these separately in the sections of this note which follow:

Section A. Target House

Section B. PWC (Proportional Wire Chamber System)

Section C. Spark Chamber System

Section D. Spectrometer Magnet

Section E. Cerenkov Counters

Section F. Calorimeters

Section G. Data Collection System.

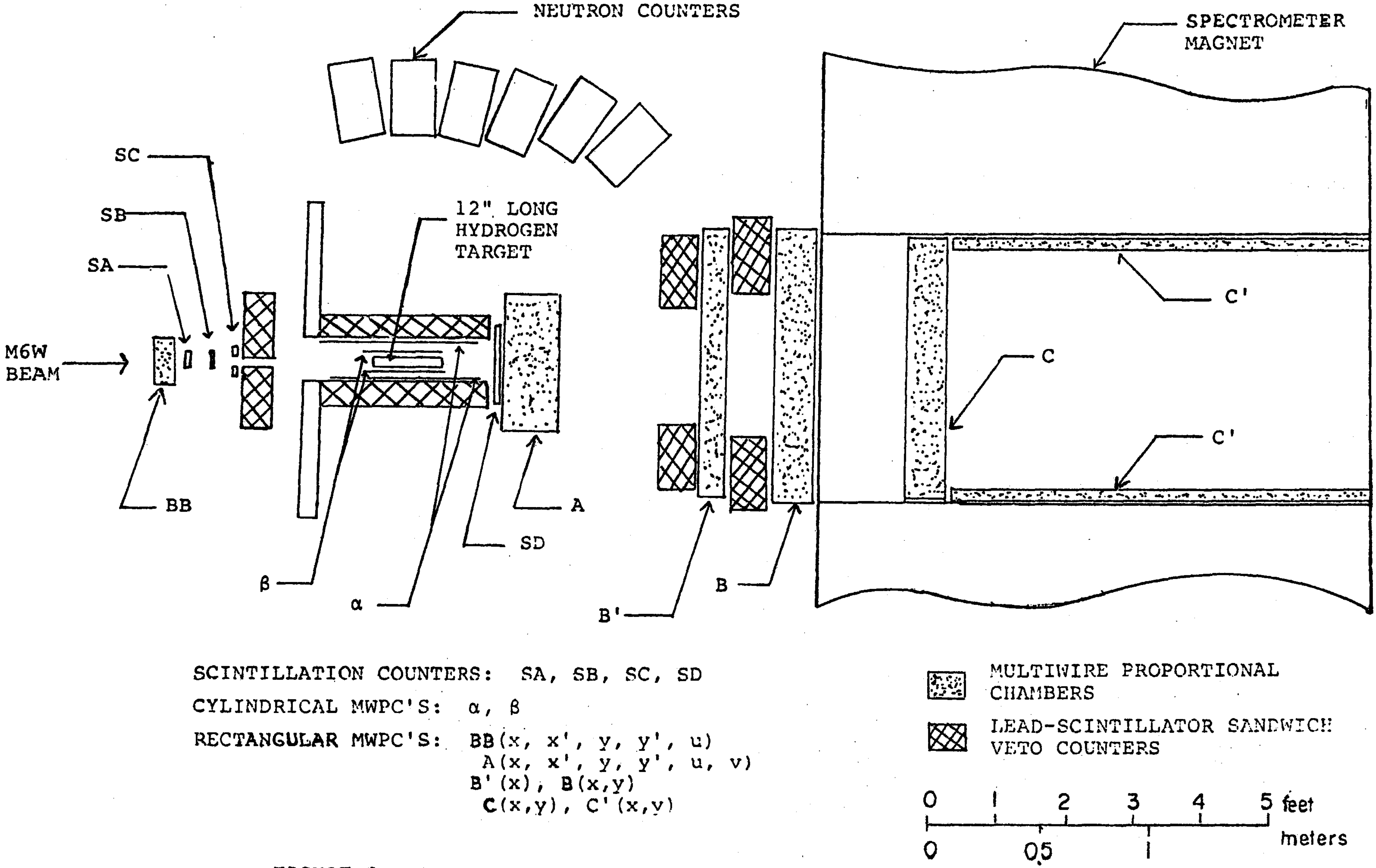


FIGURE 2. DETAIL OF THE E-110 TARGET REGION, PLAN VIEW

Section A: TARGET HOUSE

The target house consists of

a) a 12-in long, 1-in diameter liquid hydrogen target

b) two cylindrical PWC's concentric with the target

c) a cylindrical shower counter

d) shower counters located just upstream and downstream of the target; and

e) neutron counters.

Figure A-1 shows a side and end view of the target house.

Cylindrical Shower Counter

This shower counter will be used as a veto or tag for events producing slow π^o's. The cylindrical shower counter will divide the azimuth into 24 segments as shown in Figure A-1. Actually the lead is in the form of six concentric cylinders, not segmented, but the scintillators will be as in the detail shown in Fig. A-2. For each of the 24 counters, the scintillators are coupled via light pipes to a single 2" phototube (RCA 6655A). The light pipes bend outward like spokes of a wheel from the upstream ends of these counters.

Other Shower Counters

The other veto arrays consist of 12 shower counter modules arranged in 3 stations, 1 upstream and 2 downstream of the target. The upstream station consists of 2 modules, side-by-side with a 1" hole for the beam. The two downstream stations consist of 4 and 6 modules respectively arranged so as to leave a hole in the middle of each station. The 4-module station has a 15" x 6" hole while the 6-module station (located further downstream) has a hole size which can be varied between 16" x 4" to 26" x 16".

Each module is a lead-scintillator array. The modules are 25" long and 14" wide. The 6 lead sheets and 6 scintillator sheets are 1/4" thick. The 6 scintillator sheets are coupled via light pipes to a single 5" phototube (RCA 8055).

Cylindrical PWC's

The two concentric cylindrical PWC's will have 192 and 48 wires each. They will be 23" and 16" in length and will be 3.34" and 1.28" in radius, respectively. The wires run parallel to the cylinder axis. The electronics for the outer chamber essentially divides into two parts: trigger logic and current division electronics. The trigger logic determines the number of hits in the entire cylinder, or in subdivisions if so desired. The current division logic is predicated upon limiting the system to one amplifier per wire and combining a number of wires before pulse height analysis to limit the number of ADC's.

Neutron Counters

There are 18 neutron counters arranged in 4 rows of 5, 5, 4 and 4 counters covering a fraction of the azimuth. These counters are 8" in diameter, 9 5/8" in depth and filled with liquid scintillator (NE235H - mineral oil based). Each neutron counter is attached to a 2" phototube (RCA 6655A). The neutron counters will be multiplexed, in groups of 3, into CAMAC ADC's and TDC's.

TARGET HOUSE

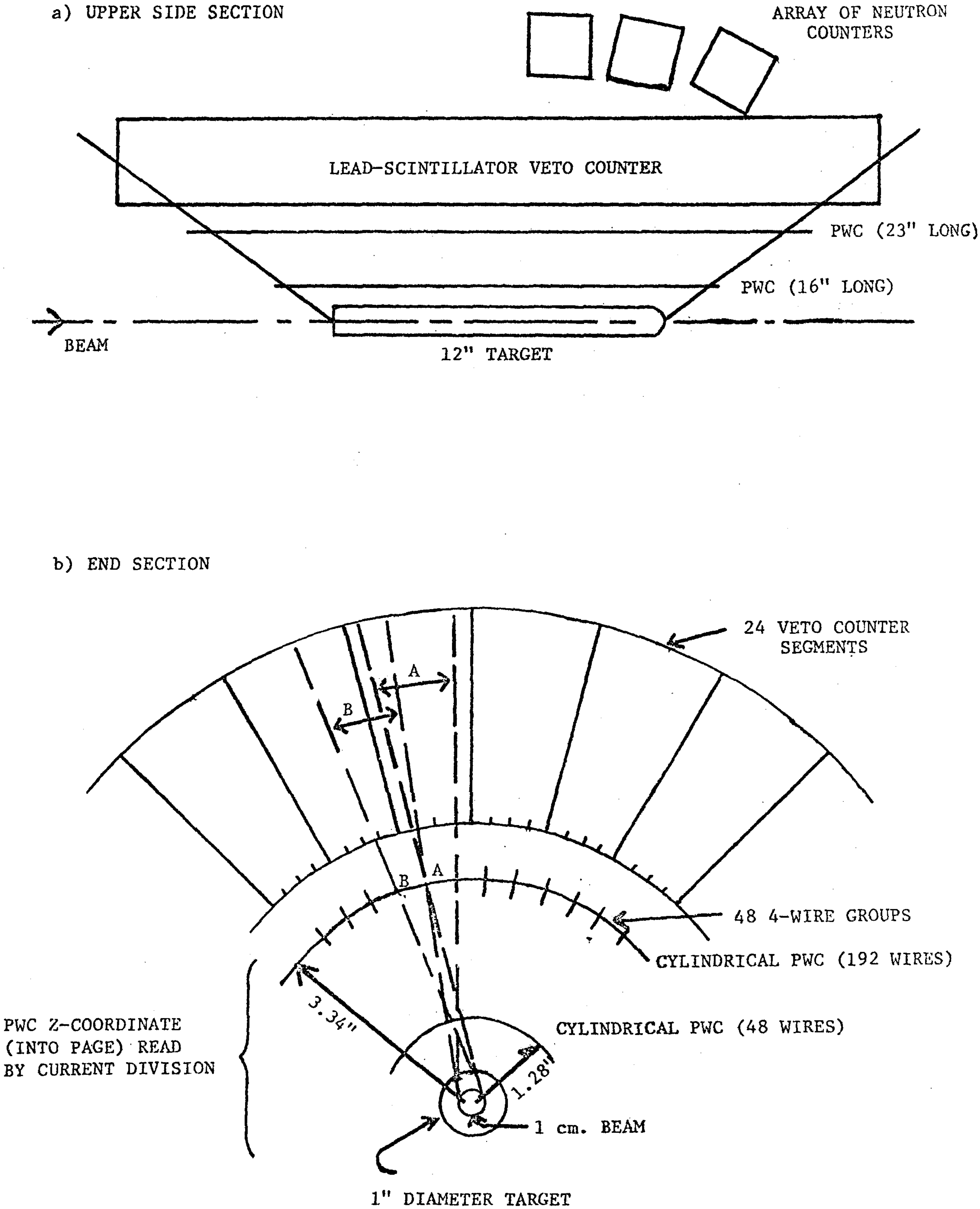
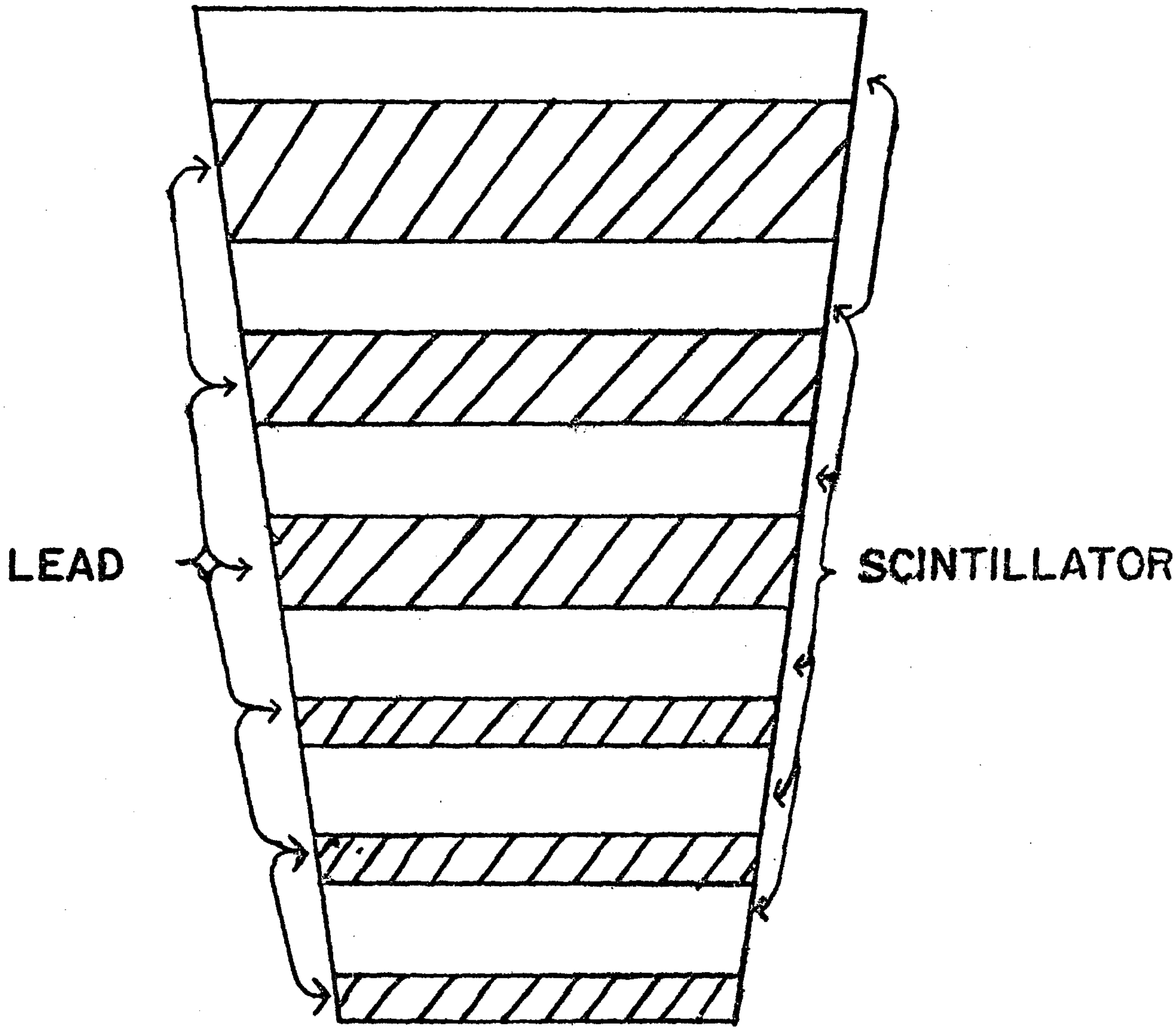


FIG. A-1

CYLINDRICAL VETO COUNTER SEGMENT DETAIL



Lead Layers: 1/8", 1/8", 1/2", 1/4", 1/4", 3/8"

Scintillator: 1/4", NE 102

Fig. A-2

Section B: Proportional Wire Chamber System

Beam PWC's

Chambers BA are two x-y modules located about 30 meters upstream, each consisting of an x-y pair of 56 wires each, with 20μ diameter anode wires spaced 13/inch and with foil cathodes. These may be staggered for better angle precision for E110.

There are five BB chambers just upstream of the target. BBV and BBW are similar to BA, 56 wires each, 13/inch, rotated 30° and 120° relative to horizontal. BBX, BBY and BBU are 64 wire planes, 26/inch, of similar construction to the A chambers below and in the x, y and 45° directions.

Cylindrical PWC's

These are two concentric cylindrical PWC's with 192 and 48 wires each, 23" long and 3.34" radius and 16" long and 1.28" radius respectively. They were described further in Section A.

A-Station PWC's

These are divided into two modules, an x-y module and a 45° rotated u-v module.

x-y module: This module consists of two x-planes staggered for higher resolution, and two y-planes likewise staggered. The cathodes are stretched wires perpendicular to the anode wires. The module is assembled in one aligned package in the sequence x, x', y, y' .

u-v module: This is a separate module, assembled like the above but containing only two anode planes, and rotated 45°.

Characteristics of A-chambers:

Anode wires: 10μ diameter - gold plated tungsten - 26 wires/inch
256 wires total/plane
Cathode wires: 50μ diameter beryllium copper, 26 wires/inch
cathode wires placed perpendicular to anode wires
Wire length: 10"
Clearing Field: Potentials are set so that all dead spaces (between cathode planes and to outside foil) are cleared by an electric field.
Gas: "Magic Gas" 20% Isobutane
4% Methylal
1/2% Freon 13B1
remainder Argon
Operating Voltage: 100 volt wide plateau at 2500-2900 volts
Anode-Cathode Gap: 3 mm.
Windows: 2 mil mylar

B and C station PWC's

These are a total of 5 planes of similar construction, divided into B' (vertical wires only), B (x and y in one module) and C (x and y, configured so as to fit into the magnet as shown). The apertures of all these modules are 40"horizontally by 26"vertically. Each vertical (x coordinate) set has 512 wires at 13 wires/inch and each horizontal (y coordinate) set has 320 wires at 13 wires/inch.

Characteristics of B and C-Chambers

Anode wires: 20μ diameter - gold plated tungsten - 13 wires/inch
320 or 512 wires/plane
Cathode wires: 100μ diameter beryllium copper, 24 wires/inch strung perpendicular to anode wires
Gas: 20% CO_2, 80% Argon
Operating Voltage: 300 volt plateau at 4,000 volts
Support wire: One support wire only, somewhat off center, on horizontal anodes only.
Anode-Cathode Gap: 0.270"

Magnet Lining-Chambers:

These chambers, just being completed as this is written, are designed to detect slow particles which do not penetrate the magnet. They are "T" shaped with larger sensitive length at the rear than between the magnet poles. The anodes are vertical, spaced 5/inch, with sensitive length 21" between the poles and 31" downstream of the poles. The 336 wires are distributed over 67" along the beam direction. They are 20μ diameter gold plated tungsten, read out with current ratio electronics (multiplexed similar to the target cylindrical PWC's) in order to determine vertical coordinates. The electronics allows use of these chambers in a multiplicity trigger. The cathodes closest to the magnet are 1/16" aluminum but the cathode facing the gap is an epoxied sandwich of 1/2" styrofoam between .030" aluminum sheets. The chambers are expected to operate on 20% CO_2 , 80% Argon.

D Station, F" PWC's:

Each of these chambers contains a single rather coarse anode plane of about 58" x 58" active area on frame of about 72" x 72" outer dimensions. For E260, five planes were used, D_x, D_y, D_u and D_v where D_u and D_v are at 15° and 105° anode direction relative to vertical, and F" in front of Cerenkov C_2.

Characteristics of D and F":

Anode wires: 50μ diameter, gold plated tungsten, 5.5 wires/inch
320 wires per plane or module, 66" long.
No support wire.
Cathode wires: 100μ diameter beryllium copper, 16 wires/inch strung perpendicular to anode wires
Gas: 20% CO_2, 80% Argon

Operating Voltage: 3,500 volts, 300 volt plateau

Anode/Cathode Gap: 3/8"
Necessary strobe width for ∿ 100% efficiency: 175 ns

F' PWC's:

These are constructed similar to the D chambers but with 4 anodes/inch and only 130 vertical wires per module. They were designed to match the calorimeter apertures.

Electronics:

Chambers BA, D_u and D_V are read out by means of MECL based amplifier-limiter-discriminator cards at the chambers, connected to shift registers on the mezzanine overlooking the experiment by means of flat 96 conductor cable. These are 704 channels.

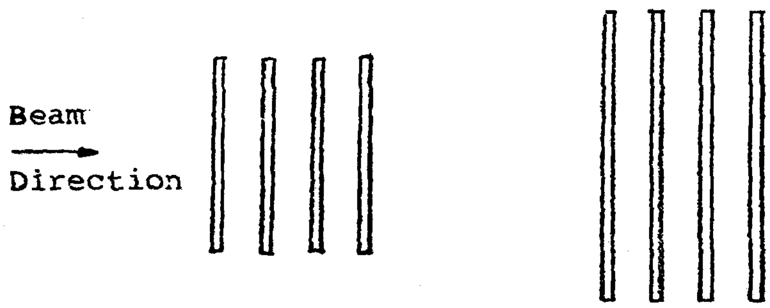
The remaining chambers (about 5,000 wires) use electronics which is mainly at the mezzanine, not at the chambers. This is required by the complex geometry in the target region. At the chamber, single transistor amplifiers on each anode (from 7 transistor array IC's) drive 50 ohm RG 174 cables with a gain of 10-25. The cables constitute the delay needed for a pre-trigger strobe. The cables are fed at the mezzanine into large CAMAC-like cards, 32 anodes per card. These have a 733 amplifier, 810 comparator and 1/5 (7496) shift register for each anode; in addition the parallel outputs from the shift registers are fed into exclusive OR's (7486) then diode mixed to generate a current sum proportional to the number of wire groups firing. This is used for multiplicity triggers in E110.

The shift registers are, upon final confirmation of a valid trigger, read out sequentially through a controller. All ∿6,000 shift registers are connected in series. The controller translates the bit stream into edge positions and widths which are transmitted to the computer as discussed in Section G.

Section C: Spark Chamber System

There are 8 modules shown schematically below:

E station	F station
4 modules	4 modules

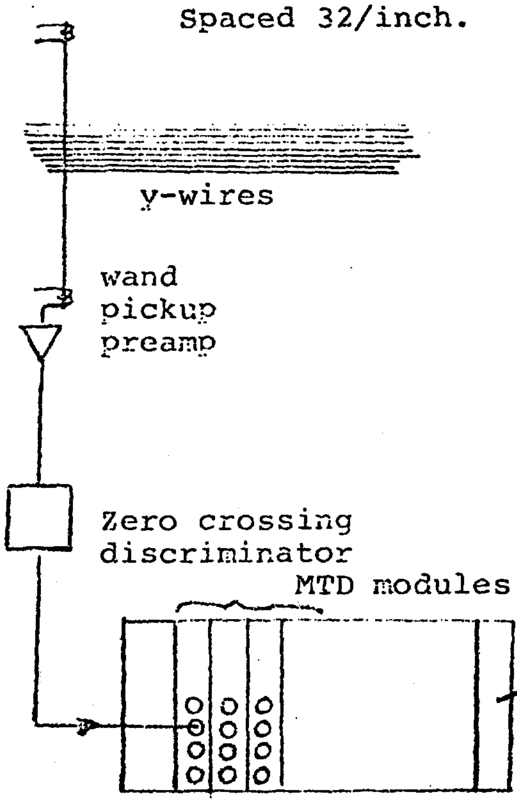


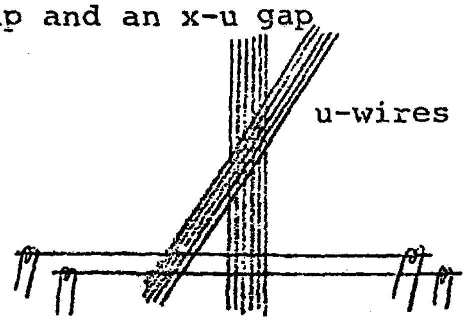
Horizontal:	8' (2.4 m)	12' (3.6 m)
Vertical:	4' (1.2 m)	6' (1.8 m)

Module Details:

Each module consists of a y-y gap and an x-u gap

Wires are 0.005" aluminum
Spaced 32/inch.





Stereo angle: $\tan \theta = 0.1$

READ IN:

Each magnetostrictive wand has pickups at each end. Thus the complete system has 6 signals (x, y, u) per module or a total of 48. The signals are amplified, discriminated and fed into MTD's (Multi-Time Digitizer. Reference: B. Bertolucci, SLAC-PUB-1177). The MTD's are mounted in a CAMAC crate together with the interface to the DMA (MTD Controller -- see Sec G). Each MTD has 4 inputs. Each channel can store up to fifteen 16 bit words (spark coordinates) and has a 4 bit word count. The least count is ~ 0.25 mm. The digitizers run at 20 mcs.

PULSERS AND CLEARING FIELDS:

One prepulser drives 8 pulsers in parallel, 1 pulser per spark chamber module. Both prepulser and pulsers use thyratrons. Both DC and pulsed cleaning fields are used. Gas mixture: 90% Ne, 10% He, ethanol.

Section D: SPECTROMETER MAGNET

The spectrometer magnet is a superconducting ferrite magnet. The magnet aperture is 4' wide by 2' high. The magnet is 8' long (poles are 4' long). The maximum $\int B \cdot d\ell$ = 25kg-m. ($p_{t\ kick}$ = 0.75 GeV/c)

Figure D-1 below shows the field uniformity along x (horizontal axis perpendicular to beam) at two values of y (vertical axis perpendicular to beam) (x = y = 0 at magnet center). Figure D-2 shows the fringe field.

The helium consumption is ≳ 10 liters/hour.

FIELD UNIFORMITY

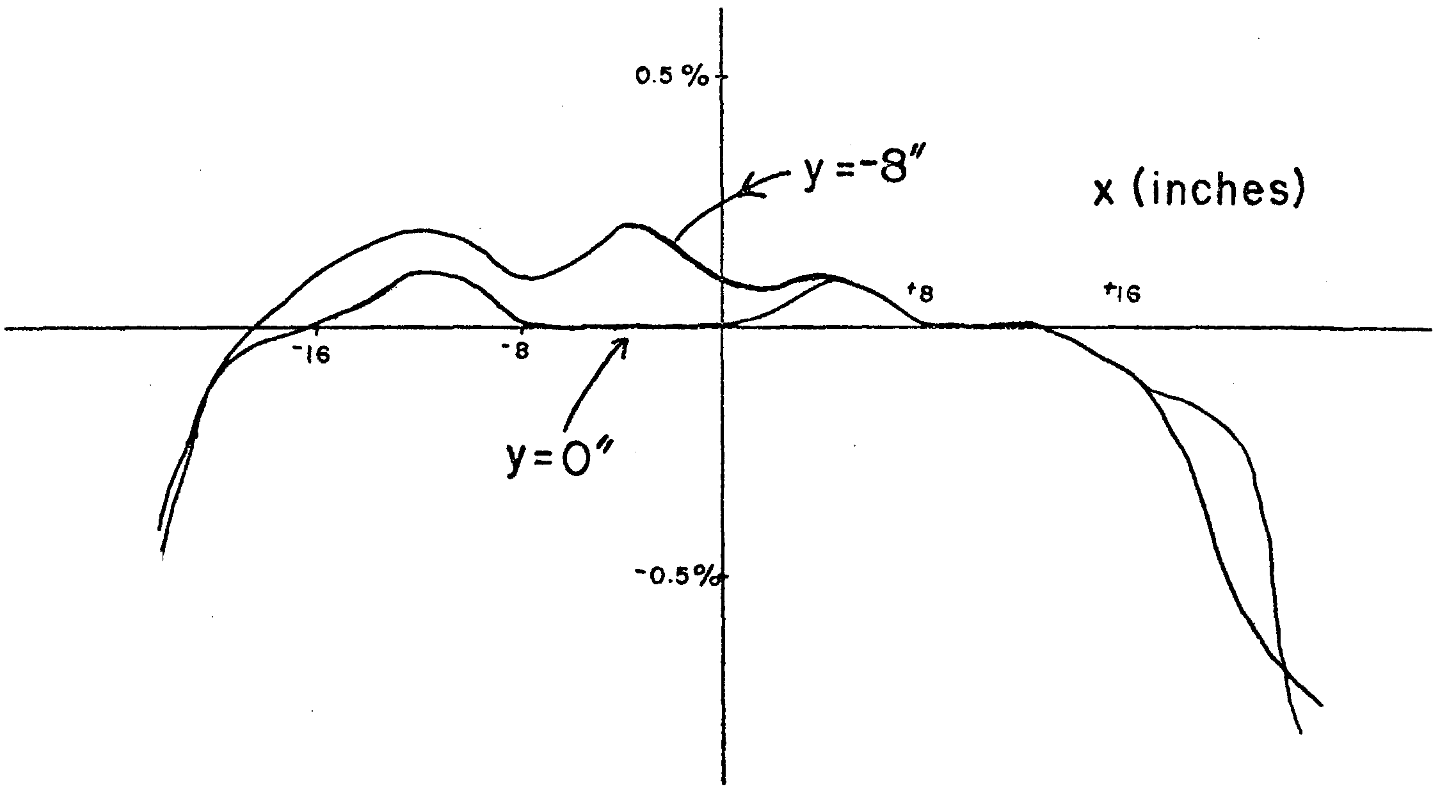


Figure D-1

FRINGE FIELD

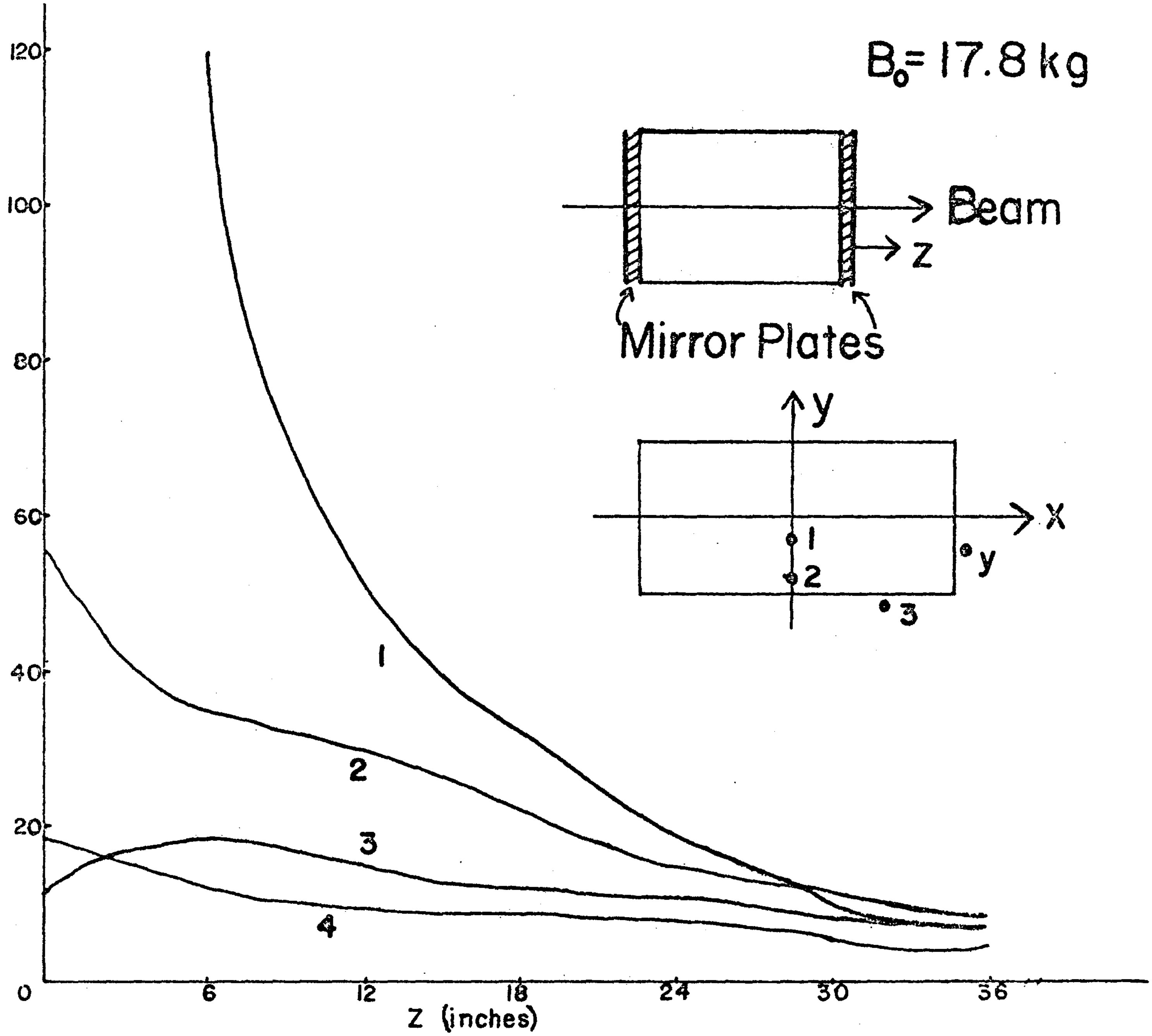


FIG. D-2

Section E: Cerenkov Counters

The MPS uses two large aperture, atmospheric pressure Cerenkov counters for particle identification. The active area of the upstream counter (C_1) is 4.5 X 1.5 meter^2. This counter is segmented by using 22 mirrors (2 rows, 11 mirrors each) each of which focuses light onto a 5 in. RCA 4522 phototube. The front end snout of C_1 is removable. With the snout in place, the radiator length of C_1 is 4.1 meter which is reduced to 2 meters when the snout is removed. During the E260 run, C_1 was operated with the snout in place. Air (pion threshold = 5.8 GeV/c) and a 2/3 He, 1/3 Air mixture(pion threshold = 9 GeV/c) were used as radiators. When running with air, the mean number of photoelectrons from β =1 pions was 8 giving an efficiency over 99 %. For the Air-He mixture, the mean number of photoelectrons for β=1 pions was 3 (95 % efficiency). The C_1 counter can be segmented with diaghrams to divide the radiator body into three regions of different index of refraction. The following table shows the thresholds for different particles for air filling and pion thresholds for different gas fillings:

<u>C_1 Air Filling</u>:

Pion threshold......5.75 GeV/c

K threshold........20.4 GeV/c

Proton threshold...38.7 GeV/c

Other C_1 Fillings:	Pion Threshold:
Freon 114	2.7 GeV/c
CO_2	4.6 GeV/c
N_2	5.1 GeV/c
He	15.0 GeV/c

The active area of the downstream counter (C_2) (see Fig. E-1) is 4 X 2 meter^2 which is segmented into 16 cells (see mirror arrangement shown in Fig. E-2) which focus light onto RAC 8854 phototubes. The radiator length for C_2 is 5.7 meters. This can be easily changed to 3.9 meters if desired. For C_2, a helium fill (pion threshold = 17 GeV/c) will yield 8 photoelectrons for β=1 pions.

The indices of refraction for both C_1 and C_2 are monitored by means of a laser refractometer.

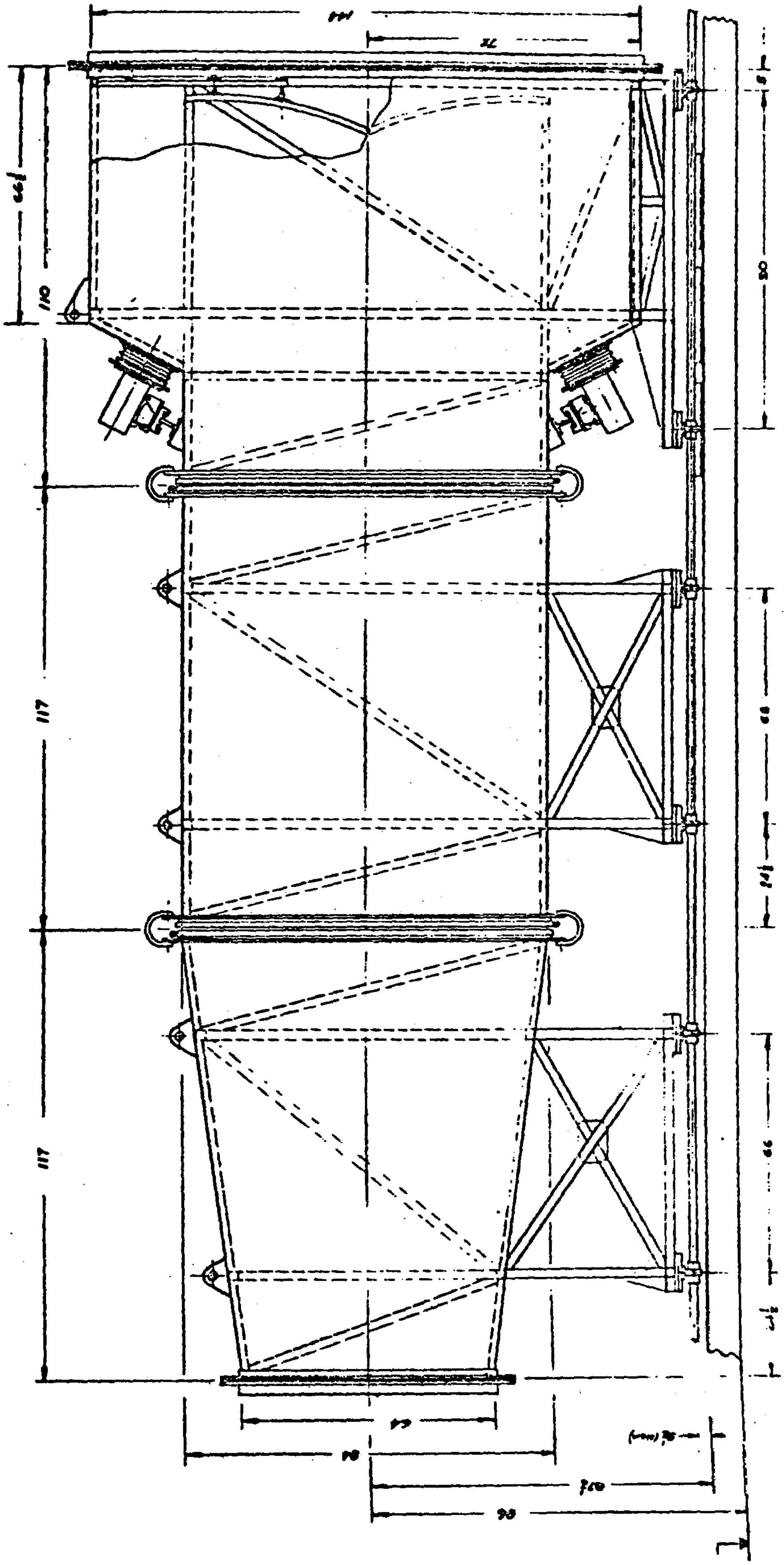


Figure E-1a

Cerenkov Counter .-Side view.

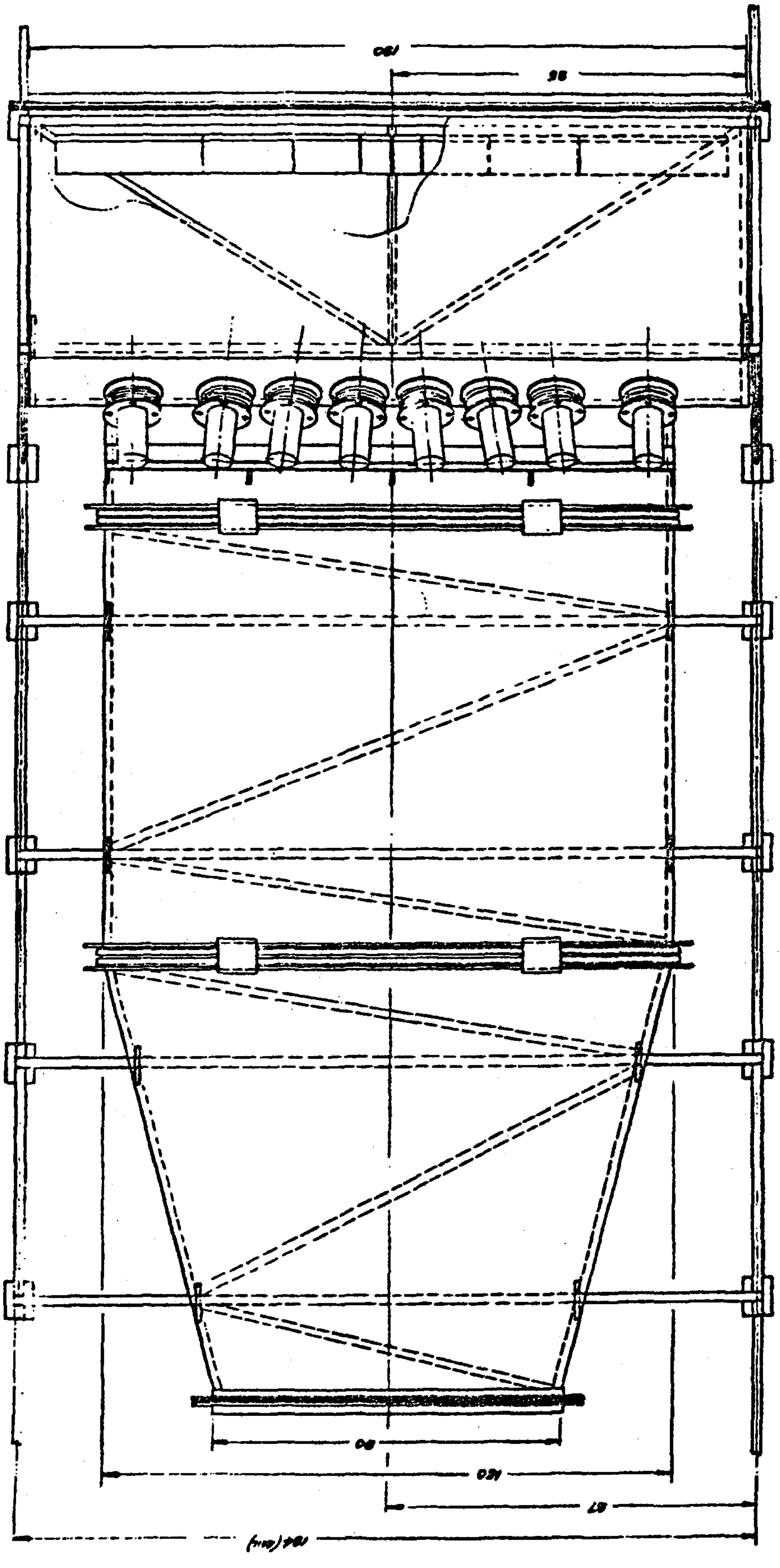


Figure E-1b
Cerenkov Counter C2-Top View

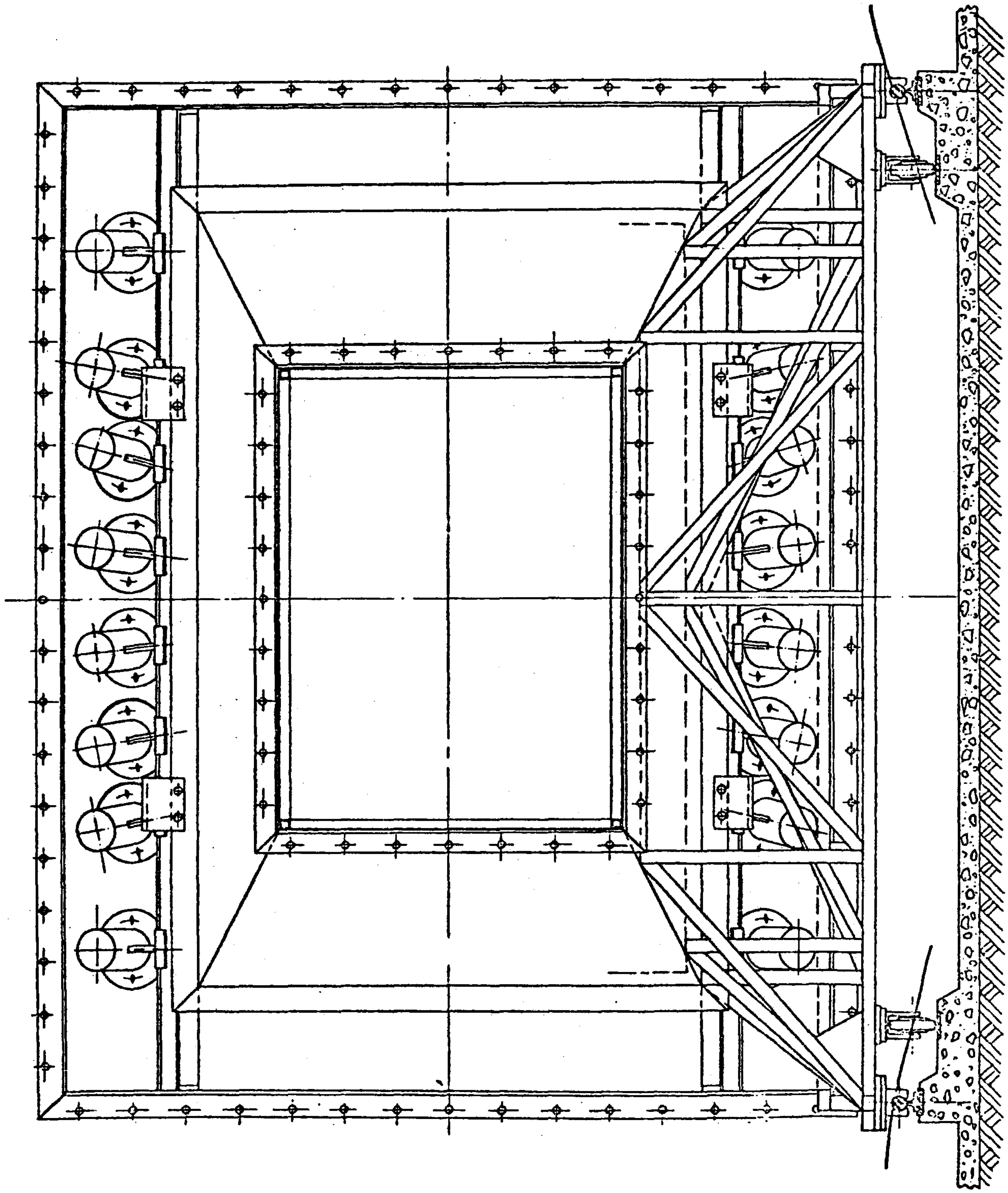


Figure E-1c

M I R R O R   S A M P L I N G

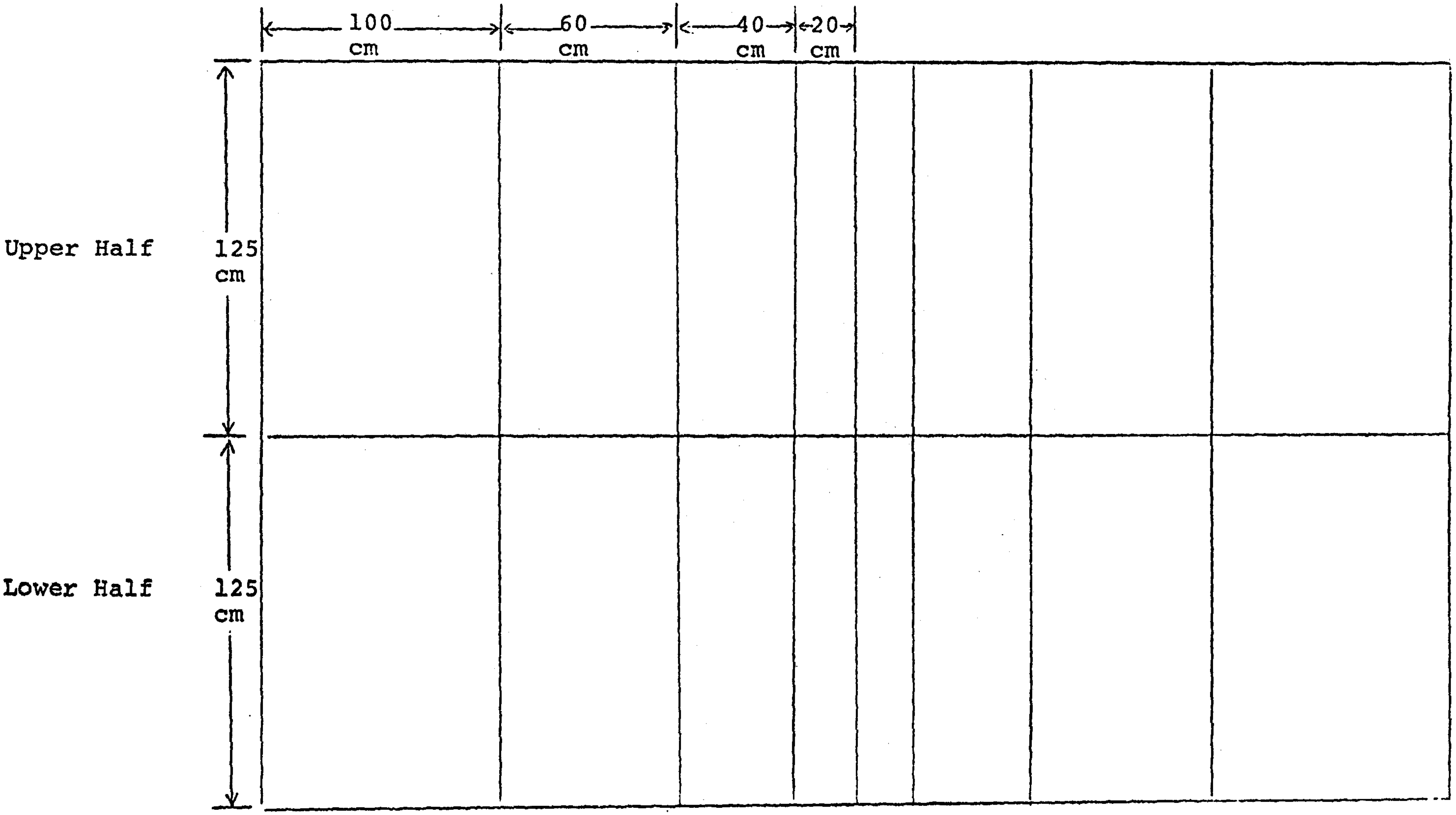


Figure E-2
Cerenkov Counter C2 Mirror Sampling (area 400 x 250 cm^2)

Section F: Calorimeters

The Multiparticle Spectrometer calorimeter array is designed to provide a fast transverse momentum trigger in the range $2 < p_t < 8$ GeV/c. A calorimeter is placed on each side of the beam line to detect particles around 90^{o} in the center-of-mass. The "90^{o} calorimeters" subtend an azimuth of 60-140 mrad in the lab corresponding (at 200 GeV/c) to 60^{o}-110^{o} in the center-of-mass. The calorimeter is in a light-tight box on wheels and can be moved toward or away from the beam.

The lead portion of the calorimeter measures electron and photon energy while the thick steel back portion measures hadron energy. There are some hadron interactions which start in the lead and give pulses in both front and back sections. The position is measured in one dimension by the modularity of the calorimeter slats (8") and in the other dimension by the ratio of phototube signals at the ends of the slats. The vertical spatial resolution for 70 GeV/c is about $\pm$ 2". The energy resolution is σ = 8% for photons and σ = 25% for hadrons at 17 GeV.

Bi^{207} sources on scintillators are glued to each phototube for calibration.

Each 90^{o} calorimeter is divided into 4 modules shown in plan view in Figure F-1. First is an array of 6 lead sheets, each followed by a scintillator, and then 15 steel plates, each followed by a scintillator. The 6 scintillators in line behind the lead are tied together into one phototube (RCA 6655A) at the top and one phototube at the bottom (only top tube shown below). All 15 scintillators in the hadron section are tied to one phototube at the top (RCA 6655A) and one phototube at the bottom. The scintillator sheets are 1/4" thick Ne-102.

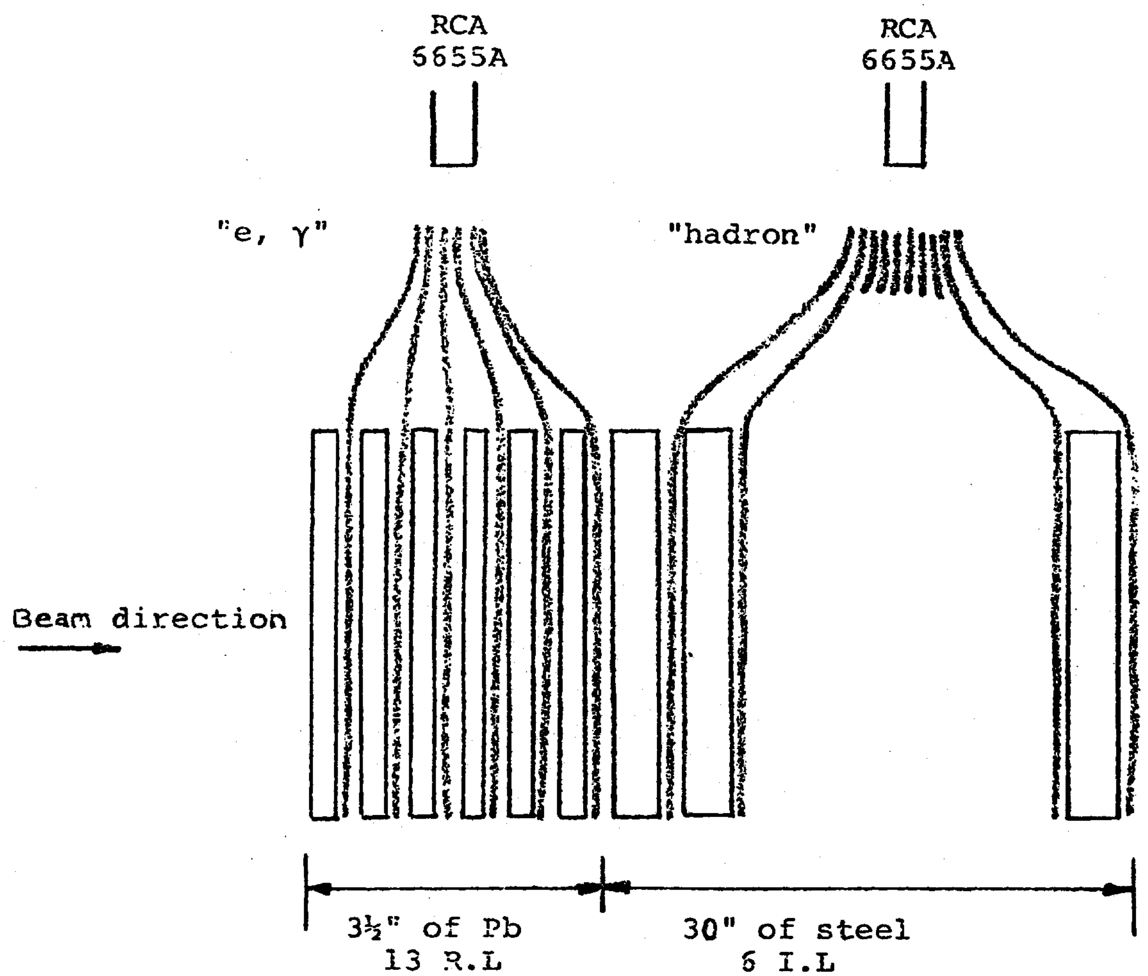
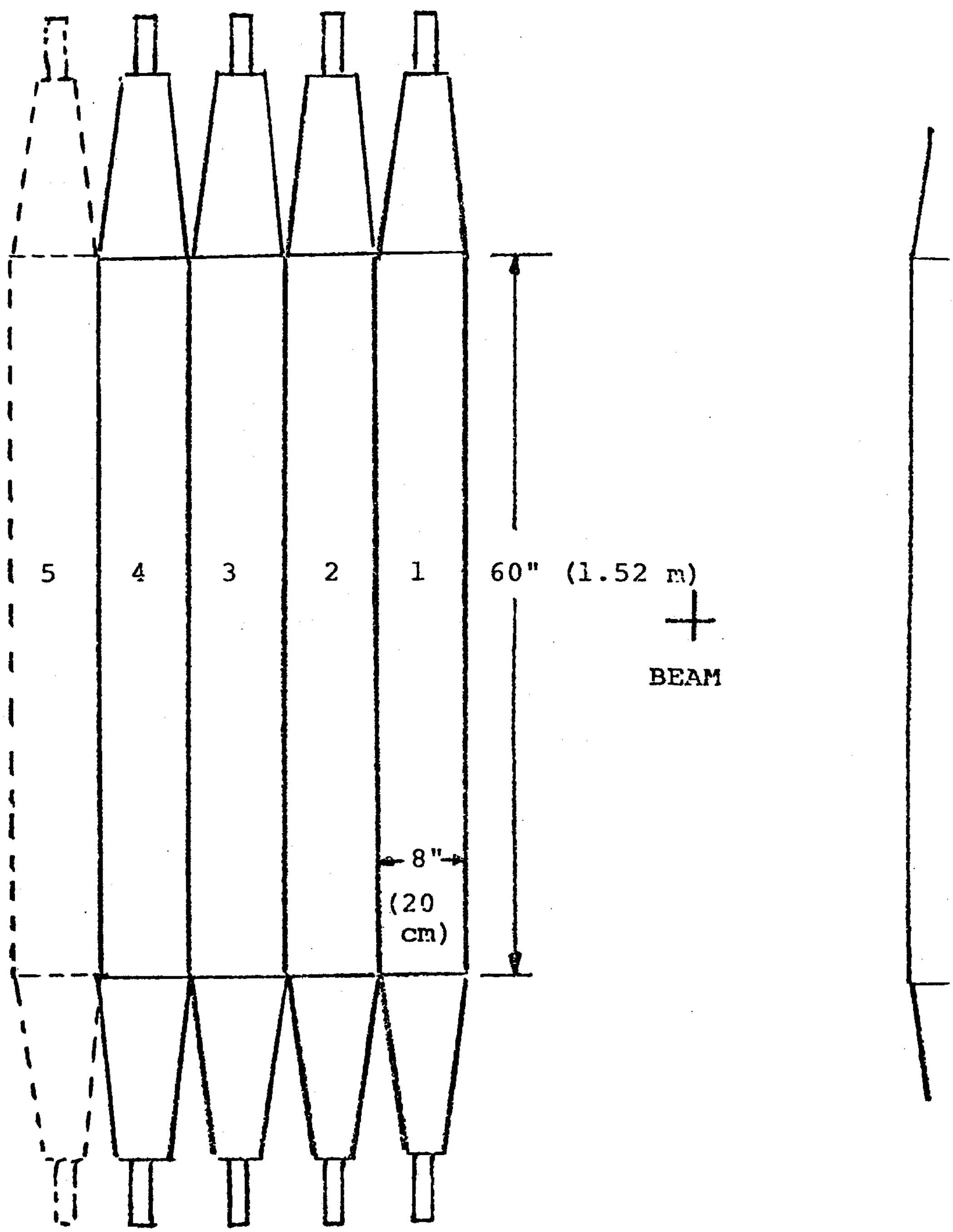


Figure F-1

Phototube signals from modules are attenuated to make the pulse heights proportional to distance perpendicular to the beam. Then, all hadron signals are added to give a pulse whose height is proportional to hadron transverse momentum. The electron signals are similarly added to give a pulse proportional to electron and photon transverse momentum. Both of these signals are added to give a total transverse momentum trigger. There is room in the steel lead structure to add a fifth module.



Section G: DATA COLLECTION SYSTEM

Overall View

Figure G-1 is a schematic of the ties between the MPS hardware and the PDP11 with its peripherals. We divide the MPS interfacing hardware into three major categories:

A. the CAMAC system;

B. the Bison Interrupt Box

C. the DMA's and Controllers for Shift Register, MTD, and Scaler Read-in

A. The CAMAC crate talks to the PDP11 through the E.G.&G. BD011 interface. The CAMAC crate contains the:

1. LAM/Latch which is responsible for interrupting the PDP11 when the external electronics indicates that an event trigger has been satisfied. The inputs (up to 16) specify which hardware are to be read in.
2. NIM/TTL Module used by the PDP11 to send START, STOP, GENERAL RESET, and RESET pulses to the trigger electronics.
3. Scalers which are 24 bit scalers read in once at the start of the beam gate and once at the end of the beam gate.
4. Lecroy ADC's used to read in pulse heights from calorimeter, C, and beam Cerenkov phototubes, and current division for cylindrical and magnet lining PWC's.
5. Drift Chamber Time Digitizers

B. The Bison Interrupt Box has two inputs to accommodate beam on-beam off interrupts. A 16-bit input register is used to interrogate the status of the hardware while a 16-bit output register is used to indicate the status of the online software.

C. The DMA's and Controllers are responsible for reading in data from the shift register (for PWC's and tagbits), from the MTD's (Multi-Time-Digitizers, for spark chambers), and from a bank of Lecroy Scalers.

The online software buffers event data onto disk during the beam spill. The time required to read in an event is dominated by the time it takes to read in data from the spark chamber MTD's which is approximately 20 msec for reading in 48 channels with 16 words/channel. Thus the data collection system is limited to ~50 events per 1-sec spill with 1200-1500 words read in/event. After beam spill the data on disk is written to tape and also made available to our on-line program, MULTI, for histogramming event attributes and making event displays on our display CRT.

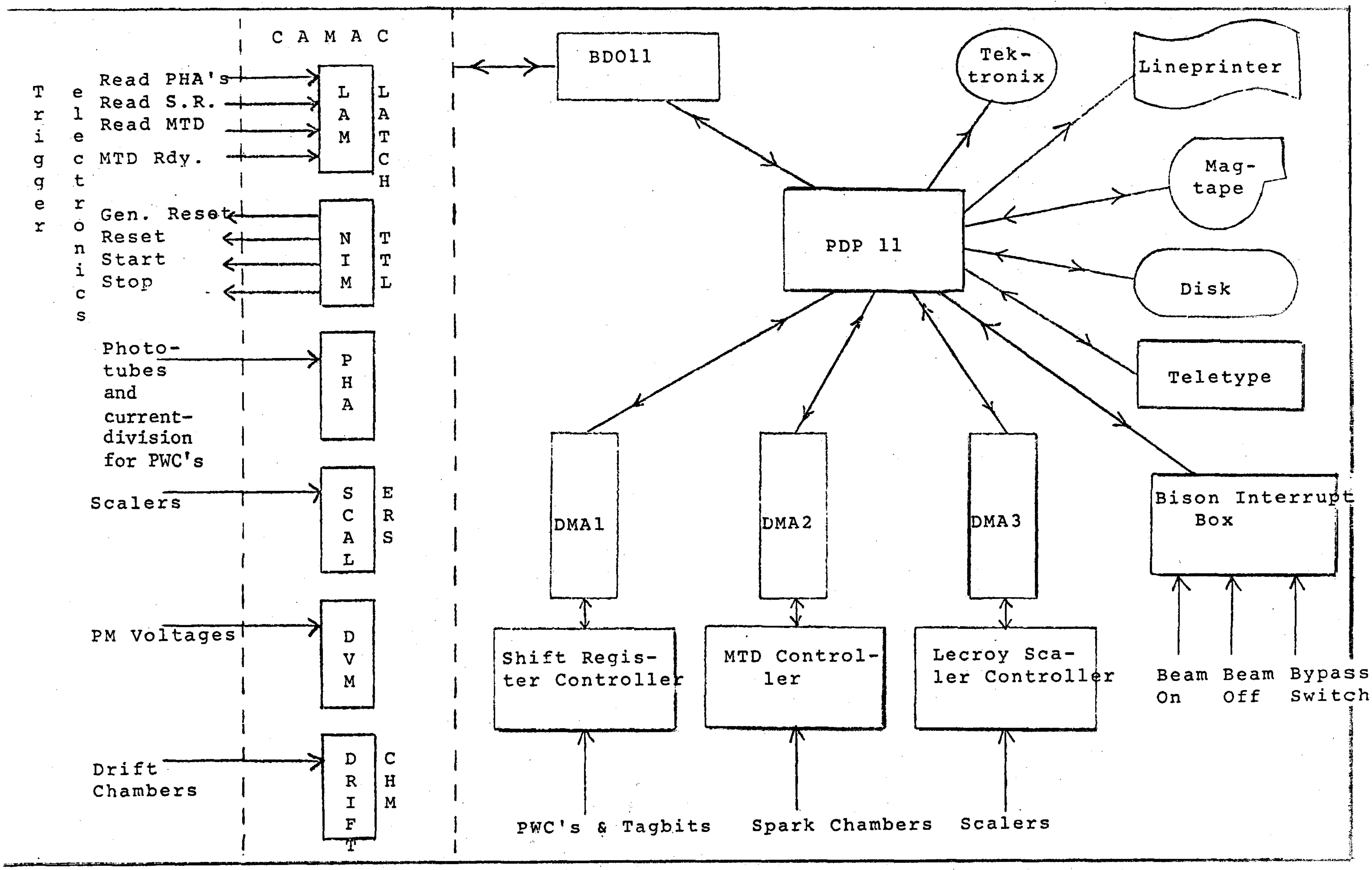


Fig. G-1. An Overview of the PDP11 - MPS Hardware Interaction

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